Dear Professor Pauli,

A few days ago Dr. Yuan told me that you had ~~been~~ kindly taken an interest ~~to~~ in ~~say~~ my Nuovo Cimento ~~the note~~ ~~which I~~ that I sent to Nuovo Cimento ~~about~~ your canonical transformations ~~about your recent work~~ ~~canonical transformations~~ ~~Today I met Miss Wu who read to me the relevant passage in your letter to her. Needless to say~~ I ~~felt~~ greatly honoured ~~pleasantly surprised~~ to learn that ~~you were able to use~~ I ~~had been~~ was of ~~some~~ any help to you in your ~~recent~~ new contributions to the theory of particles. ~~From your letter I understand that you may be wondering about what made me~~ the purpose of my work and ~~attracted me to this line of study~~ He also told me that you were wondering whether I ~~am aware~~ of what I am doing. Therefore I feel encouraged to write a few words about ~~realize the meaning~~ the purpose of my work and how I came to think along these lines ~~me interested to know that this was a means~~ Before ~~this~~ coming to Brookhaven I ~~often~~ was trying to understand Heisenberg's unitary theory and prompted by his remarks about the need to introduce isotopic spin and other quantum numbers in a more realistic theory of matter I started looking for an equation of Heisenberg's type but with new invariance properties besides the ~~usual~~ Lorentz invariance. I published two papers on the subject: Nuovo Cimento 3, 988 (1956) and 5, 154 (1957).

In the first I proposed the possible equations

$$① \quad i\gamma_\mu \partial_\mu \psi = \lambda (\bar\psi\psi)^{\frac{1}{3}} \psi$$

$$② \quad i\gamma_\mu \partial_\mu \psi = \lambda \left[(\bar\psi\psi)^2 + (\bar\psi i\gamma_5 \psi)^2 \right]^{\frac{1}{6}} \psi$$

~~where λ is dimensionless~~

both of which are conformal invariant. ~~The~~ Eq (2) has the additional invariance property ~~ψ~~ $\psi \to e^{i\gamma_5 \alpha} \psi$. ~~I also felt that such equations had~~

That is how I was led to consider your transformations I. ~~I also felt that such eq~~

In my second paper I felt that a theory of matter should, in the c-number approximation, determine the metric of space time and therefore the above equations might be used to describe the space-time structure.

In ~~those~~ equation λ_0 is dimensionless so that the self interaction of the field is of the type considered by Schwinger, and the theory has a chance of being renormalizable. ~~I heard that~~ ~~Lagrangian was experimenting with.~~ The interaction term in the Lagrangian is of the form $(\bar\psi\psi)^{4/3}$ and I heard that ~~Ruch~~ ~~Lehmann~~ was experimenting with just such interactions in his attempt to find a renormalizable non-linear spinor equation.

26 Feb 1958

Dear Prof Pauli

The day after I mailed (by special delivery) my letter ~~involving remarks on~~ about the classification of particles I received your letter dated 18 Feb 1958. Thank you very much for your penetrating remarks on Schwinger's paper which I had glanced at superficially. I was pleasantly surprised that in this connection you make remarks similar to mine on the mirror problem, namely that mirror particles are connected with particles obtained by reversing the hypercharge and may have different mass. In my last letter I was worried by the μ decay problem. In the sense I use it the mirror ~~image~~ of the electron is μ^+ and not μ^-, since the charge must also be reversed under the mirror operation. Then the experiment suggests (the Michel parameter must be ~~3/4~~ near $\frac{3}{4}$) that $\mu^- \to e^- + \nu_R + \bar{\nu}_L$. In the usual interpretation of ~~the~~ the 2-component theory ν_L is the antiparticle of ν_R, so that $\nu_R + \nu_L$ has lepton number zero, therefore μ^- and e^- have same leptonic number, ~~therefore~~ Hence μ^+ ~~cannot be the mirror of~~ would have lepton number -1 and cannot be the mirror of e^-. On the other hand if $\nu_R \neq \bar{\nu}_L$, then the 2-component theory in its present form has to abandoned which is a great pity. At this cost (e^-, ν, μ^+) would form a triplet closed under the mirror operation since both e^- and μ^+ become particles (lepton number $+1$) with opposite charge. By the way (e^-, ν, μ^+) have been considered as a triplet by Salam, Pauli ? in a recent article. To reduce the number of state of the neutrino ~~we could have~~ from 4 to 2 we could take a Majorana neutrino with $\nu_R = \overline{(\nu_R)}$, $\nu_L = \overline{(\nu_L)}$. But in this case ~~the β decay~~ ~~[illegible]~~ it becomes difficult to define the lepton number for the neutrino. There might be a way out by ~~We might~~ assuming that the lepton number changes sign not under the operation C but under PC. ~~In this case ν_R and ν_L would carry opposite leptonic number~~

You ask me about Schwinger's neutrinic charge and before knowing this I seem to have answered your question, because the neutrinic charge can be incorporated in the spinor model, being then identical with the strangeness quantum number.

I want to add the operator corresponding to the photon which I forgot to mention in my last letter. This is ~~of the~~ of the form $\bar{\Psi}\gamma\Psi + \bar{\Psi}^c\gamma\Psi^c$ which does transform like a tensor and a vector.

Thank you very much for the 2d edition of your joint paper with Heisenberg. I noticed that the strangeness of ν has again been changed. If it is changed to one in the 3d edition it will agree exactly with the model in my letter!

I am now trying to formulate the operators for the creation of particles in a more consistent and elegant way than in my last letter. ~~When I make~~ You will know immediately about any progress that I may make.

Now some items of personal news. I have heard from Prof. Chew. The radiation Lab. is willing to pay for the travel expenses of my family. I am now planning to be in Berkeley from about March 20 to May 31. I am looking forward to working with you and visiting Berkeley.

It is very kind of you to try to invite me to Zurich in 1959, I would be delighted and greatly honoured. But I have to decide what to do until then. My American Scholarship extends until the spring of 1959 and my appointment in Brookhaven is coming to an end in October 1958. Since Dyson asked me to apply to Princeton I did so, and before I received your letter telling me about your scruples to recommend me to Princeton (or the other way round) I received a letter from Prof. Oppenheimer ~~tell~~ informing me that I had been accepted.

I am specially happy about this because they will give me a supplementary allowance to make up for my meagre ICA fellowship and will provide Housing. I shall try to find out what young people will be there next fall. I shall be returning to Turkey in 1959 and after that date I would welcome any invitation to Zurich or Cern, because I feel I shall not be able to work efficiently in Turkey where living conditions now are ~~also~~ miserable and the teaching duties very heavy.

Dear Professor Pauli;

I apologize for keeping silent for such a long time. Knowing ~~the enormous vol~~ ~~your volume on correspondence~~ the ~~size~~ volume of your mail I did not want to add to it and waste your precious time by reporting the small things I had done which would be of no interests to you. During my summer in Brookhaven I had a lot of discussions with Pais, Feinberg, Goldhaber and other physicists ~~and~~, trying to learn as much as I could ~~from~~ about the experimental situation and the ~~new~~ possible theoretical interpretations to find a clue for a new direction in ~~the~~ elementary particle physics.

It seems that there is no overall symmetry of strongly interacting particles stronger than invariance under the isotopic spin group, but there are probably some additional approximate symmetry groups, the doublet approximation (use of $N_2 = \begin{pmatrix} \Sigma^+ \\ Y^0 \end{pmatrix}$, $N_3 = \begin{pmatrix} Z^0 \\ \Sigma^- \end{pmatrix}$ with $Y^0 = \frac{\Lambda^0 - \Sigma^0}{\sqrt{2}}$, $Z^0 = \frac{\Lambda^0 + \Sigma^0}{\sqrt{2}}$) instead of the singlet Λ and the triplet $\vec{\Sigma}$) being justified in the first approximation. If this symmetry were true the K charge exchange scattering of K's on nucleons would be completely forbidden. The fact that this process has a small cross section compared with elastic scattering strongly suggests that there is a class of interactions with 4-dimensional symmetry where the doublets enter and another class having only 3-dim. isospin symmetry ~~which~~ is a kind of perturbation to the doublet structure, the latter breaks this high symmetry, separates Λ from $\vec{\Sigma}$ and allows K charge exchange scattering. Therefore it seems that the group structure of strong interactions is richer than the isospin group and there is the possibility of several classes of interactions characterized with different coupling constants and different symmetry properties, to exist within the family of strong interactions.

Can one formulate any principle that would restrict the form of all these possible interactions?

It seemed to me that the best guide here is the conservation of parity in strong interactions. I tried to find out which internal symmetries were necessary in order to guarantee parity conservation in strong interactions. I collaborated with G. Feinberg on this subject since he had already shown that the hypothesis of charge symmetry and non derivative Yukawa coupling were sufficient to ensure separate conservation of C and P in pion nucleon interactions if CP is conserved.

We found that these theorems can be generalized to all trilinear interactions of baryons with π and K mesons, ~~however~~ provided ~~at least the~~ the baryons have a doublet structure. The necessary symmetries are discontinuous like charge symmetries and are independent of invariance under the isotopic spin group. Example: if $N_1 = \binom{P}{n}$ and $N_4 = \binom{\Xi^0}{\Xi^-}$ the symmetries required to ensure P conservation in K-meson baryon interactions are

(α) $N_1 \leftrightarrow N_2$, $N_4 \leftrightarrow N_3$, $K^0 \to \bar{K}^0$, $K^+ \to -K^+$

and (β) $N_1 \leftrightarrow N_3$, $N_4 \leftrightarrow N_2$, $K^0 \rightleftarrows K^0$, $K^+ \to K^-$

The product of these two symmetries is the same the product of charge symmetry in the doublet approximation and the mirror operation.

If charge independence also exists this implies very high symmetry for π and K couplings which is incompatible with experiment. At this stage we learned that Sakurai had also derived similar results in Berkeley.

Our idea for breaking this symmetry was based on the electromagnetic analogy. Charge symmetry which insures P conservation in the pion-nucleon case is approximate and yet deviations from charge symmetry do not result in deviations from P conservation because the agent responsible for the distortion of charge symmetry is the electromagnetic field whose interactions are also parity conserving due to gauge invariance.

Therefore we were led to introduce quadrilinear couplings (doublet perturbations) which owing to their structure also have to conserve P and have only 3-dimensional symmetry, thereby separating Λ from $\vec{\Sigma}$ and causing transitions forbidden in the doublet approximation – ~~All the~~ Examples of such doublet perturbation terms are discussed in a paper that we have just finished writing.

This paper is now being mimeographed and I will send you a copy as soon as it is ready. Because it is rather long you do not have to read it. The rather detailed Introduction and Conclusion should be enough to give an idea of what we have done.

These ideas might also be applied to weak interactions. In the case of the β interactions for instance, because we have a Fermi coupling, charge symmetry no longer implies ~~G~~P invariance if CP is conserved (I extend charge symmetry also to the electron-neutrino pair: $p \leftrightarrow n$, $e \leftrightarrow \nu$, since this symmetry operation is only defined in the limit of the electromagnetic forces being neglected). In this case we know that parity is violated, for instance the two-component theory of ν implies it. What additional restrictions do we get if we impose charge symmetry on the β interaction? The answer is that we obtain the V, A form. The S, T, P interactions are not invariant under charge symmetry.

One might expect that the other generalized charge symmetries α and β also play a role in weak interactions. We are now working on a paper dealing with these questions. The first results are quite encouraging: one obtains reasonable approximate selection rules that ~~are~~ would be exact if the doublet perturbations did not exist (For instance $K^+ \to 2\pi$, is nearly forbidden while $K^0 \to 2\pi$ is allowed. Experimentally one knows that $\frac{\text{rate}(K^+ \to 2\pi)}{\text{rate}(K_1^0 \to 2\pi)} \sim \frac{1}{500}$; The μ meson is still a mystery although one can associate the symmetry group of weak interactions with the symmetry (K).

The weak point in the relations we derive between CP and P for strong interactions is that we have to rely very heavily on Lagrangian formalism. The trilinear couplings must be non derivative, whereas we do envisage the possibility of having derivative ~~coupling terms~~ of the boson fields in the quadrilinear (doublet perturbing) couplings. Hence the whole thing becomes rather artificial.

In the last few weeks I tried to look for a general principle which would eliminate derivative couplings in the Yukawa term but allow them in quadrilinear couplings. To my surprise I found that such a principle exists: it is the principle of invariance with respect ~~of~~ to ordinary isotopic spin rotations where the rotation parameters are allowed to be arbitrary functions of space time. Thus one obtains gauge transformations of the second kind (the Yang Mills transformations) which are very analogous to electromagnetic gauge transformations, and which, through the intermediary of Yang-Mill, $\vec{b}_\mu$ field leads to effective 4 field interactions which have a very simple form, namely

$$f^2 \; \vec{J}_\mu \, \vec{J}_\mu$$

where $\vec{J}_\mu$ is the total isotopic spin current for strongly interacting particles and f^2 is a coupling constant characterizing the strength of the doublet perturbations. If you are interested I would be glad to give you more details. I apologize for ~~writing~~ making ~~such an incomprehensible letter~~ this letter incomprehensible by trying to summarize what I did ~~during the summer. I heard that Glaser has~~ I hope our paper will seem clearer to you.

Of course all such attempts to connect parity conservation with the symmetry properties of strong interactions will be swept clean if the recent ~~Alvarez group~~ experiments of Schwartz and Alvarez group turn out to be right: they have found that the $\Sigma - \Lambda - \pi$ interaction probably violates parity (by 3 standard deviations)

I heard that Glaser had withdrawn his objection to the indefinite metric which was related to an overdetermination of the conditions to eliminate multiple ghost states. I would like to know your present feelings about the possibility of an indefinite metric.

I am very happy at the Institute where I have very stimulating discussions with Pais, Sakurai, Nishijima and a young man J. Bernstein who is interested in more practical problems ~~...~~ in Elementary Particle physics. Oppenheimer and Pais have given me much encouragement for the work I am doing. Lee and Yang do not like my approach. Please give the regards of Saba and myself to Mrs Pauli and my greetings to Henry Stapp.

Yours sincerely,

(1)

Febr 14

Dear Prof Pauli

Thank you very much for your nice and stimulating letter which I got this morning. I do not think I can answer all your questions at once so that I had better start ~~giving the answers which~~ with the relatively easy ones.

1 — The Lagrangian. I cannot give you a complete answer on the uniqueness of the Lagrangian in q number theory. But in C number theory this is easy. Kroll's Lagrangian is the same as yours except for the sign ~~and some others~~ of the same type. This follows from the algebraic identity

a further identity is

$$(1)\qquad (\bar\psi \gamma_5 \gamma_\mu \psi)(\bar\psi \gamma_5 \gamma_\nu \psi) g^{\mu\nu} = \pm \{(\bar\psi\psi)^2 - (\bar\psi\gamma_5\psi)^2\}.$$

(2) $(\bar\psi\gamma_\mu\psi)(\bar\psi\gamma_\nu\psi)$

which was first given by Laporte and Uhlenbeck and probably also by you (in the Ann. Inst. Poincaré).

To prove it it is easier to use my notation

$$\Psi = \begin{pmatrix} \psi_1 & -\psi_4^* \\ \psi_2 & \psi_3^* \end{pmatrix}, \qquad \bar\Psi = \Psi^{-1}\,\mathrm{Det}\,\Psi = \begin{pmatrix} \psi_3^* & \psi_4^* \\ -\psi_2 & \psi_1 \end{pmatrix}$$

Further let $\bar\psi\gamma_5\gamma_\mu\psi = \cancel{S}K_\mu$, $\bar\psi\psi = \omega_1$, $\bar\psi i\gamma_5\psi = \omega_2$ (S_μ, ω_1, ω_2 are real). Then, denoting the hermitian conjugate by a dagger, we have the expressions (in C numbers),

$$\Delta = \Psi\bar\Psi = \bar\Psi\Psi = \omega_1 + i\omega_2 \qquad K = \Psi\sigma_3\Psi^\dagger = K_0 + \vec\sigma\cdot\vec K$$

$$\Delta^\dagger = \Psi^\dagger\bar\Psi^\dagger = \omega_1 - i\omega_2 \qquad \text{and } \bar K = \overline{(\Psi\sigma_3\Psi^\dagger)} = -\bar\Psi^\dagger\sigma_3\bar\Psi = K_0 - \vec\sigma\cdot\vec K$$

Now Kroll's Lagrangian is $K_\mu K_\nu g^{\mu\nu} = K_0^2 - K^2 = K\bar K = -\Psi\sigma_3\Psi^\dagger\bar\Psi^\dagger\sigma_3\bar\Psi$

$$= -\Psi\sigma_3\Delta^\dagger\sigma_3\bar\Psi = -\Delta^\dagger\Psi\bar\Psi = -\Delta^\dagger\Delta = -(\omega_1^2+\omega_2^2).$$ This proves (1).

Further let $j_\mu = \bar\psi\gamma_\mu\psi$. Again we have $j_\mu j^\mu = \psi\psi^\dagger$

$J = j_0 + \vec\sigma\cdot\vec j = \Psi\Psi^\dagger$, so that $J\bar J = \Psi\Psi^\dagger\bar\Psi^\dagger\bar\Psi = \Delta^\dagger\Delta = (\omega_1^2+\omega_2^2)$.

If we define $U = \Psi \sigma_1 \Psi^+$, $V = \Psi \sigma_2 \Psi^+$

so that $u_\mu = R\{\bar{\psi} \gamma_\mu \psi^c\}$ $v_\mu = Im\{\bar{\psi}\gamma_\mu\psi^c\} = R(\bar{\psi}\gamma_5\gamma_\mu\psi^c)$

we also have

$$u_\mu u^\mu = v_\mu v^\mu = k_\mu k^\mu = -(\omega_1^2 + \omega_2^2).$$

Now if one forms other possible invariant

$$(\Psi \sigma_3 \bar{\Psi})(\Psi \sigma_3 \bar{\Psi})^+ = (\Psi \sigma_3 \Psi)^2 = (\omega_1 + i\omega_2)(\omega_1 + i\omega_2) = \omega_1^2 \pm \omega_2^2 + 2i\omega_1\omega_2$$

$$(\omega_1^2 - \omega_2^2)^2 + 4\omega_1^2\omega_2^2 = (\omega_1^2 + \omega_2^2)^2$$

$\omega_1^2 \omega_2^2$. There are other invariants like $\omega_1^2 \omega_2^2$ but

they are of a higher degree.

My idea was based on the observation that the four 4-vectors

$$
(3)\quad \begin{cases}
U^{(0)}_\mu = \bar{\psi}(x)\gamma_\mu \psi(x) \\
U^{(3)}_\mu = \bar{\psi}(x)\gamma_5 \gamma_\mu \psi(x) \\
U^{(1)}_\mu = \mathrm{Re}\{\bar{\psi}(x)\gamma_\mu \psi^c(x)\} \\
U^{(2)}_\mu = \mathrm{Im}(\bar{\psi}\gamma_\mu \psi^c)
\end{cases}
$$

the first of which is time-like and ~~the~~ the other 3 space-like, form an orthogonal ~~system of~~ ~~offer~~ set of vectors at each point of space-time, a set ~~of vectors~~ which can be used as a local coordinate system. (The orthogonality of $U^{(0)}$ and $U^{(3)}$ is well known, but I don't know if anybody else remarked the existence of such a tetrad. [published this in a Turkish Journal]) Conversely such a coordinate system determines ψ. Then I was separately able to show that Eq. (2) (not (1)) defines the structure of an special affine space-time with the metric $ds^2 = ((\bar{\psi}\psi)^2 + (\bar{\psi}\gamma_5\psi)^2)^{\frac{1}{2}}(c^2dt^2 - dx^2)$.

~~where~~ ~~the function~~ $[(\bar{\psi}\psi)^2 + (\bar{\psi}\gamma_5\psi)^2]^{\frac{1}{6}} = f$ ~~satisfies the simple non linear equat~~ and satisfies $\Box f = R f^3$ (R is the contracted curvature tensor).

~~(4) $\Box f = R f^3$~~

~~where R is the contracted~~ curvature tensor.

Now ~~suppose~~ a word about the relation of your Pauli's canonical transformations II with the transformations of the above tetrad.

~~We can write $U^{(\kappa)}_\mu = \Omega^{(\kappa)}_{\mu\nu} \delta_\nu$~~

~~where Ω is an orthogonal matrix~~,

(4) In a Lorentz transformation $U^{(\kappa)}_\mu \to L_\mu{}^\nu U^{(\kappa)}_\nu$ only the

~~But we can also define a rest frame rotation matrix Λ~~

indices μ are affected. But ~~in~~ a transformation like

(5) $U^{(\kappa)}_\mu \to U^{(\lambda)}_\mu \omega_\lambda{}^\kappa$

is Lorentz invariant and only affect the bracketed indices. In the special case where ω is the ~~rotatio~~ 3-dimensional rotation matrix $U^{(0)}_\mu$ is ~~not affected~~ changed, only $U^{(1)}_\mu, U^{(2)}_\mu, U^{(3)}_\mu$ are transformed into each other.

If you like this is a rest frame rotation.

Now the Lorentz transformation (4) induces on ψ the transformation

(4') $\psi \to L\psi$ where L is the familiar Lorentz matrix whereas the transformation induced by (5) (in the case of ω being a rotation matrix) is

(5') $\psi \to a\psi + b\gamma_5\psi^c \qquad |a|^2 + |b|^2 = 1$

which is just Pauli's transformations (2).

The set (3) is also invariant ~~for~~ ($U^{(\kappa)}_\mu \to U^{(\kappa)}_\mu$ under Pauli transf. I: $\psi \to e^{i\gamma_5\alpha}\psi$ [illegible] $U^{(\kappa)}_\mu \to U^{(\kappa)}_\mu$

~~Now suppose~~ the gauge transformations are obtained by taking $b = 0$, so that ~~if~~ if we bring the system $U^{(k)}_{\mu}$ to rest, $U^{(0)}$ being the time axis, and the others defining local cartesian axes $O\xi$, $O\eta$ and $O\zeta$, then the gauge transformation is equivalent to a rotation round the spin axis $O\zeta$. Yang remarked that Rotations round $O\xi$ and $O\eta$ have no direct physical meaning in quantum theory as they would imply ~~the~~ a mixing of positive and negative energy states corresponding to different eigenvalues of the charge operator ~~as remarked by Yang to me~~.

After that, following Heisenberg's (from his review article) remark that isotopic spin might be better understood by means of charge conjugation I tried to relate your transformation (which includes both charge conjugation and a rotational structure) to isotopic spin which exhibited the same character and that was the subject of my Nuovo Cimento note. I was hoping in this way to introduce isotopic spin in my equation (2) which already has the $i\gamma_5$ invariance.

Since then I have been trying to extend your gauge transformations as to include the strangeness gauge transformation discovered by D'Espagnat and Prentki in an attempt to understand strangeness better. I am also studying ~~the relation between~~ trying to see if T, C, P ~~and~~ isotopic spin reflections can be introduced in a natural manner as I felt ~~they must be related~~ that there must be a deep connection between strangeness conservation and separate conservation of C and P. To this end I have been compelled to use ~~Dirac~~ the algebra of the γ matrices (4×4) matrices as the σ matrices (2×2) matrices do not ~~per~~ allow such an extension.

~~To represent~~ is

To represent isotopic multiplets I ~~arrange the~~ ~~a representation in which classify~~ I represent spinor fields ~~according to~~ by matrices $\Psi_{\mu\nu}$ where μ refers to the spin coordinates (classified according to the eigenvalues of γ_5 and σ_3 in a representation in which both these matrices are diagonal ($\gamma_5 = \begin{pmatrix} I & 0 \\ 0 & -I \end{pmatrix}$ $\sigma_3 = \begin{pmatrix} \sigma_3 & \\ & \sigma_3 \end{pmatrix}$), and the index ν refering to the charge states $+e$, $0^{(+)}$, $0^{(-)}$ and e^- where $0^{(+)}$ and $0^{(-)}$ correspond to state representing 0 charge but ~~behaving in the opposite way under~~ with different transformation properties C (or CP). For instance The N, Ξ system is represented by $\Psi = (p, n, \Xi^0, \Xi^-)$ where each letter represents a column 4-spinor. The $\Lambda, \vec{\Sigma}$ system is represented by $\Phi = \left(\Sigma^+, \frac{\Sigma^0 - i\Lambda^0}{\sqrt{2}}, \frac{\Sigma^0 + i\Lambda^0}{\sqrt{2}}, \Sigma^- \right)$. ~~Switching of the sign of Λ^0 corresponds~~ to the ~~operation $\Phi \to \Phi$~~

The charge gauge transformation for both fields is

$$\Psi \to \Psi e^{i\frac{\gamma_5 + \sigma_3}{2} q}, \quad \Phi \to \Phi e^{i\frac{\gamma_5 + \sigma_3}{2} q}$$

Now σ_3 belongs to the triplet $\sigma_1, \sigma_2, \sigma_3$ and γ_5 to the triplet ~~$\tau_3 = \gamma_5$~~, $\tau_1 = \gamma_0$, $\tau_2 = i\gamma_0\gamma_5$, $\tau_3 = \gamma_5$ $\vec{\sigma}$ and $\vec{\tau}$ commute. ~~Now~~ for an isotopic spin rotation we have for the doublet-doublet field

$$\Psi \to \Psi e^{i\vec{\sigma}\cdot\frac{\vec{\xi}}{2}}$$

and for the scalar-triplet field

$$\Phi \to \Phi e^{i\frac{\vec{\sigma} + \vec{\tau}}{2}\cdot\vec{\xi}}$$

$$\Phi \to e^{i\frac{\vec{\sigma}+\vec{\tau}}{2}\cdot\vec{\xi}} \Phi$$

Switching of the sign of Λ^0 corresponds to the operation

$$\Phi \to \Phi \frac{1 + \vec{\tau}\cdot\vec{\sigma}}{2}.$$

~~Spin zero bosons~~ The π meson may be represented by the matrix

$$\Pi = i\vec{\pi}\cdot\vec{\sigma}$$

And the K meson by $\left(K^0 = \frac{K_1^0 + iK_2^0}{\sqrt{2}}, \quad K_2^0 = K_3, \quad K^+ = \frac{K_1 + iK_2}{\sqrt{2}} \right)$

$$K = K_1^0 + i\vec{K}\cdot\vec{\tau}$$

Under charge gauge transformation we have $\Pi \to \Pi e^{-i\frac{\gamma_5 + \sigma_3}{2}q} \Pi e^{i\frac{\gamma_5+\sigma_3}{2}q} = e^{-i\frac{\sigma_3}{2}q} \Pi e^{i\frac{\sigma_3}{2}q}$, $K \to e^{-i\frac{\gamma_5+\sigma_3}{2}q} K e^{i\frac{\gamma_5+\sigma_3}{2}q} = e^{i\frac{\gamma_5}{2}} K e^{i\frac{\gamma_5}{2}}$

and Under isotopic spin transformations we have

$$\Pi \to e^{-i\vec{\sigma}\cdot\frac{\vec{\xi}}{2}} \Pi e^{i\vec{\sigma}\cdot\frac{\vec{\xi}}{2}} \quad \text{and} \quad K \to e^{-i\vec{\tau}\cdot\frac{\vec{\xi}}{2}} K$$

Now the equation of motion of the Ψ operator may be written as

$$i\gamma_\mu \partial_\mu \Psi = m\Psi + g\gamma_5 \Psi \Pi + \Phi (f_1 + f_2 \vec{\sigma}\cdot\vec{\tau}) K \qquad f_1 \frac{3 + \vec{\sigma}\cdot\vec{\tau}}{2} + f_2 \frac{1 - \vec{\sigma}\cdot\vec{\tau}}{2}$$

~~Besides~~ invariance under isospin rotations it is also invariant under

$$\Psi \to \Psi e^{i\gamma_5 \alpha}; \quad K \to K e^{i\gamma_5 \alpha}, \quad \Phi \to \Phi, \quad \Pi \to \Pi$$

which is just d'Espagnat and Prentki's isospinor number gauge transformation leading to strangeness conservation

~~There is a similar equation for Φ~~

Now I come to ~~the definition~~ a remark about of the charge conjugation

$\psi \to \psi^c$ which carries particles into antiparticles and charge $+e$ into charge $-e$.

~~If we define $\psi^c = \gamma_2 \psi^* = C \bar{\psi}$ $(\bar{\psi} = \psi^+ \gamma_0)$, $C = \gamma_2$~~

Take the nucleon wave function

$$N = (p, n, 0\ 0) = \Psi \frac{1+\gamma_5}{2}$$

If we define $\psi^c = \gamma_2 \psi^*$

then $N \to (p^c, n^c, 0\ 0)$

and p^c represents a solution corresponding to $+$ve charge and negative energy.

To get the correct charge ~~behaviour~~ state of the antiparticle we must

define $\Psi^{c'} = \gamma_2 \Psi^* \gamma_2^{-1}$ as in quantized field theory

then ~~$N \to$~~ $(p^c, n, 0\ 0) \to (0\ 0, -n^c, p^c)$

and ~~Ψ~~ $N^{c'}$ ~~belongs~~ ~~to~~ the right eigenvalue of the charge operator

$(\ )\gamma_{\underline{5+\sigma_3}}$. But this is just ~~the product~~ essentially the product of C with isotopic spin rotation of 180° round the ~~second~~ second iso-axis not that of C' is conserved ~~there is also reflection invariance~~ invariance must repeal to the ~~in isospace~~. This seems to give a clue to the ~~relation conservation~~ relation ~~But~~ ~~the~~ ~~old~~ above definition of ~~charge conjugation~~ of C between ~~invariance~~ invariance under isotopic spin reflection (conservation of strangeness) and conservation

~~$\Psi \to \gamma_2 \Psi^* \gamma_2^{-1}$, $\Phi \to \gamma_2 \Phi^* \gamma_2^{-1}$ implies~~

of charge conjugation. -1 $\quad \gamma_2\sigma_3 = \gamma_2\gamma_1\gamma_2$

But such considerations are tentative and they may not make sense to you in that case I would be very grateful to have the opportunity

$\Pi \to \gamma_2 \Pi^* \gamma_2^{-1}$, $\quad (f_1 + f_2 \vec{\sigma}\cdot\vec{\tau}) K \to \gamma_2 (f_1 + f_2 \vec{\sigma}\cdot\vec{\tau}) K^* \gamma_2$

$f_1 + f_2 \tau_2\sigma_2 + (\tau_3 \sigma_3 + \tau_1\sigma_1)$

$K \to \gamma_2 K^* \gamma_2^{-1}$

and $(f_1 + f_2 \vec{\sigma}\cdot\vec{\tau}) \to \gamma_2 (f_1 + f_2 \vec{\sigma}\cdot\vec{\tau})^* \gamma_2^{-1} = \gamma_2 (f_1 + f_2 \vec{\sigma}\cdot\vec{\tau}) \gamma_2$

$$= f_1 + f_2 \tau_2\sigma_2 - f_2(\tau_1\sigma_1 + \tau_3\sigma_3)$$

Since we have the form $f_1 + f_2 \tau_2\sigma_2$ what is left

$\psi \to \psi e^{i\gamma_2 t}$

Then we have the new quantum number $\psi \to \psi e^{i\gamma_2 \alpha}$ $\quad K \to e^{-i\gamma_2\alpha} K e^{i\gamma_2 \alpha}$

γ_2 commutes with $\vec{\sigma}\cdot\vec{\tau}$.

I hope to speak to you in New York and be put on the right track again. If I am deviating too far from it I can always send you the abstract of the application of my method to weak interaction which it seems to give a justification of the A V interaction. Sincerely yours,

The Brookhaven ...

$$\Phi e^{i\frac{\gamma_5+\sigma_3}{2}q}\left(f_0 + f_3\sigma_3\gamma_5 + f_1\beta\sigma_1 + f_2 i\beta\gamma_5\sigma_2\right) e^{-i\gamma_5\frac{q}{2}} K e^{i\gamma_5\frac{q}{2}}$$

$$\Phi e^{i\frac{\gamma_5+\sigma_3}{2}q} e^{-i\frac{\gamma_5+\sigma_3}{2}q}(f) e^{i\frac{\gamma_5+\sigma_3}{2}q} e^{i\frac{\gamma_5+\sigma_3}{2}q} K e^{-i\frac{\gamma_5+\sigma_3}{2}q} \qquad e^{i\frac{\gamma_5+\sigma_3}{2}q}$$

To have under charge gauge

$$K \to e^{i\gamma_5\frac{q}{2}} K e^{-i\gamma_5\frac{q}{2}}$$

$$\Phi \to \Phi e^{-i\frac{\gamma_5+\sigma_3}{2}q}.$$

$$f \to e^{-i\frac{\gamma_5+\sigma_3}{2}q} f e^{i\frac{\gamma_5+\sigma_3}{2}q}$$

$$= f_0 + f_3\sigma_3\gamma_5 + e^{i(\gamma_5+\sigma_3)q}\left(f_1\beta\sigma_1 + f_2 i\beta\gamma_5\sigma_2\right)$$

one can have

$$\Phi\left(f_0 + f_3\sigma_3\gamma_5\right.$$

$$\Phi = \Sigma + \Lambda \qquad \Lambda = (\Phi + \Lambda\ \Lambda\Phi)$$

$$\Phi - \Sigma = \Lambda$$

$$\Phi - \Phi\frac{3+\vec\sigma\cdot\vec\tau}{2} = \Lambda = \Phi\frac{1-\vec\sigma\cdot\vec\tau}{2}$$

We must show that isotopic spin rotations leave Λ^0 invariant

Φ can be written as $\underbrace{\Phi\frac{3+\vec\sigma\cdot\vec\tau}{2}}_{\Sigma} + \underbrace{\Phi\frac{1-\vec\sigma\cdot\vec\tau}{2}}_{\Lambda}$

We must have $\Phi\frac{1-\vec\sigma\cdot\vec\tau}{2}$

$$\Phi e^{i\frac{\sigma_1+\sigma_3}{2}\theta}\frac{1-\vec\sigma\cdot\vec\tau}{2} = \Phi\frac{1-\vec\sigma\cdot\vec\tau}{2}.$$

Dear Prof. Pauli;

Thank you very much for your notes on the TCP theorem. I shall endeavour to study them. They certainly do not confirm your claim that you ~~don't know as much as the~~ ~~are not an experts in the fields~~ are not an expert in field theory.

The first day I got back to Brookhaven I was asked to give a talk on your talk, which I gladly did. Although it was a second hand and much watered down version of your Columbia lecture it aroused unusual interest. I have also received ~~Ilssa~~ a letter from three young theoreticians from the Institute, that fortress of the "experts" who courageously confess to be interested in your new field theory and ask me for preprints of my own work. They seem to be intent on working along the lines you suggested. All this seems to indicate ~~prove~~ that, in spite of the experts' violent objections, you have attained your principal objective ~~in assembling U.S. physicists~~ which was to ~~make in~~ free the unprejudiced physicists from the current dogmas.

After giving my talk I was taken to bed by an attack of flu which again caused me to delay the letter on the strange particles which I had promised to write to you in a reasonably legible fashion. In the letter I sent you to Zürich I had tried to give a phenomenological description of

T.R. (
Lee Oehme ~~, Yang~~, Phys. Rev. 106, 340 (1957)
Curtis ~~, Lewis~~, Phys. Rev. 107, 543 (1957)
Morita (1953)
)

baryons and mesons representing all the fields by 4×4 matrices. The second stage was to try to derive the phenomenological symmetry properties ~~from the~~ of these individual fields from a single matrix field. This part is not yet rounded up but

$$\Psi^c = \begin{pmatrix} p_1 & n_1 & n_1' & p_1' \\ p_2 & n_2 & n_2' & p_2' \\ p_3 & n_3 & n_3' & p_3' \\ p_4 & n_4 & n_4' & p_4' \end{pmatrix} \qquad \Psi^c = \begin{pmatrix} p_1 \\ \\ \\ \end{pmatrix}$$

$$n = \begin{pmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{pmatrix} \qquad n^c = \begin{pmatrix} -n_4^x \\ n_3^x \\ n_2^x \\ -n_1^x \end{pmatrix}$$

$$\frac{(1+\gamma_5)}{2} p = \begin{pmatrix} p_1 \\ p_2 \\ 0 \\ 0 \end{pmatrix} \qquad \begin{pmatrix} n_1 \\ n_2 \\ 0 \\ 0 \end{pmatrix}^c = \begin{pmatrix} 0 \\ 0 \\ n_2^x \\ -n_1^x \end{pmatrix}$$

$$\frac{1-\gamma_5}{2} n^c = \begin{pmatrix} 0 \\ 0 \\ +n_2^x \\ -n_1^x \end{pmatrix}$$

$$\chi = \frac{1+\gamma_5}{2} p \pm \frac{1-\gamma_5}{2} n^c = \begin{pmatrix} p_1 \\ p_2 \\ -n_2^x \\ +n_1^x \end{pmatrix} \qquad \chi^c = \begin{pmatrix} n_1 \\ -n_2 \\ p_2^x \\ -p_1^x \end{pmatrix} \qquad \gamma_5 \chi^c = \begin{pmatrix} n_1 \\ -n_2 \\ -p_2^x \\ p_1^x \end{pmatrix}$$

$$\begin{pmatrix} p_1 & n_1 \\ p_2 & n_2 \end{pmatrix} \begin{pmatrix} a & -b^x \\ b & a^x \end{pmatrix} = \begin{pmatrix} a p_1 + b n_1 & -b^x p_1 + a^x n_1 \\ a p_2 + b n_2 & -b^x p_2 + a^x n_2 \end{pmatrix}$$

$$a\chi \mp b\gamma_5 \chi^c = \begin{pmatrix} a p_1 + b n_1 \\ a p_2 - b n_2 \\ a n_2^x - b p_2^x \\ -a n_1^x - b p_1^x \end{pmatrix} \qquad \begin{pmatrix} p_1 & n_1 \\ p_2 & n_2 \end{pmatrix}$$

$$p \frac{1+i\gamma}{2} + n \frac{1+i\gamma}{2} i e_1 \qquad \begin{pmatrix} p_1 & 0 \\ p_2 & 0 \end{pmatrix} + \begin{pmatrix} n_1 & -n_4 \\ n_2 & n_3 \end{pmatrix}$$

$$\begin{pmatrix} n_1 & 0 \\ n_2 & 0 \end{pmatrix} \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} = \begin{pmatrix} 0 & n_1 \\ 0 & n_2 \end{pmatrix}$$

I hope to give you a comprehensible account of it by next week when I ~~feel better~~ ~~hope to be feeling better~~ feel better. You see I am proceeding semi empirically and trying to guess the structure of the fundamental 4×4 field equation from symmetry properties of the known particles - after I ~~get~~ acquire a feeling for these invariance properties I shall try, following your suggestions ~~to try~~ to find general conditions for the functions appearing in the vacuum expectation values. But ~~for~~ at that stage I will need your help and will be in a much better position if Prof. Chew and Dr. Judd can ~~get me~~ arrange for me to go to Berkeley for a while.

By the way, the correct structure of the Lagrangian in q number theory, using the matrix $\Psi = \begin{pmatrix} \psi_1 & -\psi_4^* \\ \psi_2 & \psi_3^* \end{pmatrix}$ the first column of which is $\frac{1+\gamma_5}{2}\psi$ and the second column $\frac{1-\gamma_5}{2}\psi^c$, is the following

$$L = Tr\left\{ \left[(\partial_0 + \vec{\sigma}\cdot\vec{\nabla})\Psi\right]\Psi^\dagger + \lambda(\Psi\bar{\Psi})(\Psi\bar{\Psi})^\dagger \right\}$$

where $\bar{\Psi} = \Psi^{-1}\,\mathrm{Det}\,\Psi = \begin{pmatrix} \psi_3^* & \psi_4^* \\ -\psi_2 & \psi_1 \end{pmatrix}$. This is invariant against $\Psi \to \Psi U$ (U: unitary), whatever the commutation relations of Ψ.

Yours sincerely.