$|\Delta S|=1, |\Delta I|=1/2$ rule with two charged intermediate boson fields
d'Espagnat, Bernard

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$|\Delta S|=1, |\Delta I|=\frac{1}{2}$ Rules with Two Charged Intermediate Boson Fields.

B. D'ESPAGNAT

CERN - Geneva (*)

(ricevuto il 29 Giugno 1960)

Summary. — The rules $|\Delta S|=1$ for non leptonic decays and $|\Delta I|=\frac{1}{2}$ are accounted for by a theory in which weak interactions are due to charged intermediate bosons that have no neutral counterpart. Leptonic decays of strange particles where the total charge of the leptons is zero are thereby forbidden, in accordance with experiment. Observable differences with the prediction of the Lee and Yang theory are discussed. The theory gives arguments in favour of the existence of a decay mode of the cascade particle into a nucleon and leptons with a coupling constant equal to that of the leptonic decay mode of the Λ , i.e. with a decay rate about twenty times smaller than the rate for the normal Ξ -decay.

1. — Introduction.

In a recent paper ⁽¹⁾, LEE and YANG investigated the consequences of the following three propositions:

i) All weak interactions are transmitted through an intermediate boson field w .

ii) The K_1^0, K_2^0 mass difference is small ($<10^{-5}$ eV), or, in other words there are no $\Delta S = \pm 2$ among the usual non leptonic weak interactions.

iii) The $|\Delta I|=\frac{1}{2}$ rule holds for the strangeness non conserving decays of particles, where I is the total isospin of the strangely interacting particles. This investigation led them quite naturally to a scheme in which

(*) On leave of absence from the University of Paris.

(1) T. D. LEE and C. N. YANG: to be published.

a) There exist two complex intermediate boson fields w and w^0 , representing altogether four kinds of particles w^+ , w^- , w_a^0 , w_b^0 which bear some similarity with the $K^+K^-K_1^0K_2^0$ complex.

b) These fields have dual isospin properties in the sense that they behave as components of an isospinor when coupled to the strangeness-non-conserving current and as an isoscalar and the components of an isovector when coupled to the strangeness-conserving current⁽²⁾. For that reason they are called schizons.

Although the schizon scheme is attractive it is not a unique consequence of propositions i), ii), iii). In the first place it can be modified and generalized by keeping assumption a) and dropping assumption b) so that the w 's are not schizons any more. This rather trivial generalization is briefly described in Section 4 together with its experimental implications. The main purpose however, of the present paper is to describe an altogether different theory which assumes the existence of four charged intermediate bosons w^+ , w^- , v^+ , v^- (i.e. two complex boson fields) and of no neutral ones. It is shown below (Section 2) that propositions i), ii) and iii) are compatible with such an assumption, iii) being either an exact statement or a statement which is exact only in the limit of an infinite intermediate boson mass, depending on the choice of the parameters. In the latter case the $|\Delta I| \geq \frac{3}{2}$ admixtures due to a finite intermediate boson mass are discussed and shown to be small for reasonable values of the parameters involved.

The main interest of a theory based on charged intermediate bosons only is that it implies the validity of a fourth proposition:

iv) All decays that involve one lepton pair among the decay products are strictly forbidden apart from electromagnetic effects when the total charge of this pair is zero.

This fact is important, for proposition iv) is indeed as well rooted in experimental facts as proposition iii) for instance. In order to keep this property in mind, we suggest that the w and v particles should be called « vetons ».

LEE and YANG⁽¹⁾ have described a number of observable predictions of the schizon theory. Many of these are the same in the veton theory but some others are different and could serve as experimental tests between the two schemes. A detailed comparison of the predictions of the two theories is made in Section 4.

⁽²⁾ In this respect also, the Lee and Yang w particles are rather similar to the K 's, particularly if one thinks of the « M space » interpretation of the $|\Delta I| = \frac{1}{2}$ rule (B. D'ESPAGNAT, J. PRENTKI and A. SALAM: *Nucl. Phys.*, 5, 447 (1958)).

2. - Non-leptonic interactions.

The simplest way to write down a four-baryon interaction that satisfies the $|\Delta I|=\frac{1}{2}$ rule is to multiply an isoscalar current with a current which is the component of an isospinor; here it is, moreover, required that these currents should be charged. This leads in a straight-forward way to the weak interaction Lagrangian

$$(1) \quad L'' = (\bar{\Xi} \cdot N)(\bar{p}A) + \text{h. c.},$$

where (as everywhere below) the factors $i\gamma_\mu(1+\gamma_5)$ corresponding to the $V-A$ coupling scheme are assumed to be present inside each bracket and where $(\bar{\Xi} \cdot N)$ means the scalar product of the two isospinors $(\bar{\Xi}_0, \bar{\Xi}_-)$ and $\begin{pmatrix} p \\ n \end{pmatrix}$:

$$(2) \quad (\bar{\Xi} \cdot N) = (\bar{\Xi}_0 p) + (\bar{\Xi}_- n),$$

$(\bar{\Xi} \cdot N)$ is an isoscalar and $(\bar{p}A)$ is a component of an isospinor so that (1) gives a strict $|\Delta I|=\frac{1}{2}$ rule. This is true to any order in the strong interaction coupling constants and implies no assumption whatsoever as to the relative values of these coupling constants or of the N and Ξ masses. Eq. (1) on the other hand involves no neutral current. These simple facts make (1) suitable as a starting point for the development of the theory and indeed are the basis of the two schemes *A* and *B* described below. Eq. (1) however involves no strangeness-conserving current so that some transformations or adjunctions are necessary before it can be used.

2'1. *First simple model.* - Eqs. (1) and (2) give

$$(3) \quad L'' = (\bar{\Xi}_0 p)(\bar{p}A) + (\bar{\Xi}_- n)(\bar{p}A) + \text{h. c.}.$$

By taking advantage of the identity

$$(4) \quad (\bar{\psi}_1 \psi_2)(\bar{\psi}_3 \psi_4) = (\bar{\psi}_3 \psi_2)(\bar{\psi}_1 \psi_4)$$

one can now exchange $\bar{\Xi}_-$ and $\bar{p}$ in the second term of (3). This gives

$$(5) \quad L'' = (\bar{\Xi}_0 p)(\bar{p}A) + (\bar{p}n)(\bar{\Xi}_- A) + \text{h. c.}.$$

L'' is a part of

$$(6) \quad L' = (a\bar{p}n + a^{-1}\bar{A}\bar{\Xi}_-)(a\bar{n}p + a^{-1}\bar{\Xi}_-A) + (b\bar{p}\bar{\Xi}_0 + b^{-1}\bar{p}A)(b\bar{\Xi}_0 p + b^{-1}\bar{A}p),$$

a and b being arbitrary real coefficients, and indeed L'' is the only part of L' which can contribute to the non leptonic decays of strange particles, for the other terms in L' all have $\Delta S = 0$. Therefore L' also satisfies a strict $|\Delta I| = \frac{1}{2}$ rule. To the first order in L' there is, moreover, no $\Delta S = \pm 2$ transition in agreement with recent experimental results ⁽³⁾. Thus L' is consistent with both propositions ii) and iii).

The assumption that weak interactions are due to intermediate bosons (proposition i)) can now be easily introduced. Let us define two complex vector fields w_μ and v_μ which describe two charged bosons of each charge (the index μ is dropped in what follows) and let us replace L' by

$$(7) \quad L = [f_1(\bar{p}n) + f_2(\bar{\Lambda}\Xi^-)]_w + [f'_1(\bar{p}\Xi_0) + f'_2(\bar{p}\Lambda)]_v + \text{h. c.},$$

with the condition

$$(8) \quad f_1 f_2 = f'_1 f'_2, \quad m_w = m_v,$$

which ensures that, in the limit $m_w = m_v = \infty$, eq. (7) produces the same effects as (6). In the limit $m_w = m_v = \infty$, (7) therefore describes non-leptonic

Fig. 1. - Some lowest order graphs in Λ -decay, the weak interactions being described by (7).

decays that obey strict $|\Delta I| = \frac{1}{2}$, $|\Delta S| = 1$ rules. If, on the other hand, the masses m_w and m_v are chosen large but finite, the $|\Delta S| = 1$ rule remains strictly valid as before but, in contrast to what happens in Lee and Yang's case, the $|\Delta I| = \frac{1}{2}$ rule becomes approximate (even with absence of electromagnetic interactions). This is due to the fact that the finite intermediate boson masses make L' a non-local interaction, with the effect that there is no more a strict identity between (3) and (5).

As an illustration of how the weak interaction effec-

⁽³⁾ F. MULLER, R. W. BIRGE, W. B. FOWLER, R. H. GOOD, W. HIRSCH, R. P. MATSEN, L. OSWALD, W. M. POWELL, H. S. WHITE and O. PICCIONI: *Phys. Rev. Lett.*, **4**, 418 (1960).

tively operates in a particular case, Fig. 1 shows some of the lowest order graphs pertaining to Λ -decay. It is interesting to notice that graphs of types (a) in Fig. 1 give a strict $|\Delta I|=\frac{1}{2}$ rule irrespective of the veton mass while graphs of type (b) give a $\Delta I=\frac{3}{2}$ admixture which vanishes only for infinite veton masses. A similar distinction holds of course for higher order graphs. Under such circumstances a reliable estimate of the $\Delta I=\frac{3}{2}$ admixture as a function of the intermediate boson mass is not easily obtained. It seems, however, that for a mass of the order of the nucleon mass this admixture is presumably rather small ⁽⁴⁾, even in the simplified version here described. One can, however, make it even smaller by generalizing the theory in the manner described below.

2'2. *Second simple model.* — Another, remarkably simple model ⁽⁵⁾ which satisfies propositions i), ii), iii) and iv) is obtained directly from (1), by assuming that interaction (1) is due to an intermediate boson v . It is

$$(9) \quad f_1(\bar{p}n)w + \{f'_3[(\bar{p}\Xi_0) + (\bar{n}\Xi_-)] + f'_2(\bar{p}\Lambda)\}v + \text{h. c. .}$$

Indeed, proposition iii) is in this model an *exact* statement for any value of m_v : this follows from the fact that, if v is considered as an isoscalar ⁽⁶⁾, the terms which multiply f'_3 and f'_2 are an isoscalar and an isospinor component respectively. As for the term in f_1 its necessity appears in connection with leptonic couplings and the description of β and pion decays.

2'3. *A more general version of the theory.* — A more general version of the veton theory, which admits (7) and (9) as special cases, is obtained by applying

(4) Preliminary lowest order calculations gave roughly 50% $\Delta I=\frac{3}{2}$ admixture under the most unfavourable and highly unlikely assumptions that all graphs (a) of Fig. 1 are negligible, that $m_v=0$ and that the cut-off is infinite.

(5) If the existence of an unstable and (e.g. positively) charged baryon X^+ having hypercharge 2 and isospin zero is postulated, then propositions i) to iv) can be made exact statements by choosing a weak interaction Lagrangian of the type

$$f(\bar{p}n)w + [f'(\bar{X}_+A) + f''(\bar{p}\Lambda)]v + \text{h. c. .}$$

This interesting fact, which was pointed out by Dr. PRENTKI in a private discussion of the ideas here described, has led the author to consider the simple interaction Lagrangian described by (9) and by scheme B below, which has the same property without having the disadvantage of postulating the existence of a new particle. Our thanks are due to Dr. PRENTKI for this suggestion and other critical remarks on the content of the theory.

(6) An isopseudoscalar if reflections are considered (B. D'ESPAGNAT and J. PRENTKI: *Nucl. Phys.*, 1, 33 (1956)).

(4) to a fraction only of the second term in (3) and by applying to the resulting expression the same arguments as those which lead from (5) to (7). The result is

$$(10) \quad L = [f_1(\bar{p}n) + f_2(\bar{A}\Xi_-)]w + [(f'_1 + f'_3)(\bar{p}\Xi_0) + f'_3(\bar{n}\Xi_-) + f'_2(\bar{p}A)]v + \text{h.c.}$$

with

$$(8) \quad f_1 f_2 = f'_1 f'_2$$

(10) leads to an exact $|\Delta I| = \frac{1}{2}$ rule for an infinite veton mass. It reduces to (7) for $f'_3 = 0$ and to (9) for $f_2 = f'_1 = 0$. Eq. (9) gives no $|\Delta I| \geq \frac{3}{2}$ admixture whatsoever. Therefore, if y is, for a given process, the ratio (discussed in Section 2'1) of $|\Delta I| \geq \frac{3}{2}$ to $|\Delta I| = \frac{1}{2}$ matrix elements that follow from (7) alone, this same ratio takes, with Lagrangian (10), the (smaller) value

$$(11) \quad y' = \frac{f'_1}{f'_1 + f'_3 \alpha} y,$$

where α is the ratio of the $|\Delta I| = \frac{1}{2}$ matrix elements produced by (7) and (9) respectively when $f'_3 = f'_1$. As a matter of fact $\alpha \approx 1$ whenever y is not too large. Eq. (11) is used below for a rough quantitative estimate of the $|\Delta I| \geq \frac{3}{2}$ admixture with special choices of the parameters.

3. - Leptonic couplings and specification of coupling constants.

The leptonic interactions of vetons are given by the Lagrangian

$$(12) \quad L_i = [f_e(\bar{\nu}e_-) + f_\mu(\bar{\nu}'\mu_-)]w + [f'_e(\bar{\nu}e_-) + f'_\mu(\bar{\nu}'\mu_-)]v + \text{h. c. } (^7).$$

The leptonic decays of strange particles then take place through the emission of a virtual veton by (10) followed by its absorption by (12). This has a first important consequence: owing to the fact that both $(\bar{A}\Xi_-)$ and $(\bar{p}A)$ are components of isospinors, all decays of strange particles which involve a lepton pair among the decay products obey a strict $|\Delta I| = \frac{1}{2}$ rule, where I is the total isospin of the strongly interacting particles in the initial and final states. They therefore also obey the $\Delta Q/\Delta S = 1$ rule which is a consequence of the former (and of the fact that the lepton pair is charged). The situation is thus identical in this respect to the one which prevails in the schizon theory. The numerous consequences of these rules have been explored before, espe-

(⁷) For the sake of completeness let us mention here that ν and ν' could be exchanged in one of the square brackets of (12).

cially by FEYNMAN and GELL-MANN ⁽⁸⁾ and by OKUBO, MARSHAK, SUDARSHAN, TEUTSCH and WEINBERG ⁽⁹⁾.

The next problem is to choose the coupling constants in (10) and (12) in such a way as to correctly reproduce the experimental data. The most important of these is the near equality between β -decay, π -decay and μ -decay coupling constants which gives

$$(13) \quad f_1 f_e = f_1 f_\mu = f_e f_\mu + f'_e f'_\mu.$$

Another important fact is the existence of leptonic decays of K particles and the existence and relative scarcity of

$$(14) \quad \Lambda \rightarrow p + e^- + \bar{\nu}.$$

These facts are compatible with relations

$$(15) \quad f_2 f_e + f'_2 f'_e \approx f_2 f_\mu + f'_2 f'_\mu \approx 0.25 f_1 f_e.$$

Finally, the $\Delta S=2$, leptonic decays

$$(16) \quad \begin{cases} \Xi^0 \rightarrow p + e^- + \bar{\nu} \\ \Xi^- \rightarrow n + e^- + \bar{\nu} \end{cases}$$

have not been observed, although phase-space calculations show that their rate should be almost equal to the observed Ξ -decay rate if the relevant coupling constant were the same as in β -decay's. Considering that nearly 20 Ξ -particles have been observed up to now, this gives the two inequalities

$$(17) \quad (f'_1 + f'_3) f'_{e,\mu} \leq 0.25 f_1 f_e,$$

where $f'_{e,\mu}$ stands for f'_e and f'_μ .

It is rather unfortunate that the experimental information on processes (16) is so meagre. In what follows two models are described which correspond to the two extreme assumptions (A) that (16) is completely forbidden, and (B) that (17) is very nearly an equality.

Scheme A. — Here we assume that neither (16) nor the corresponding μ -decay can happen, i.e. that

$$(18) \quad f'_e = f'_\mu = 0.$$

⁽⁸⁾ R. P. FEYNMAN and M. GELL-MANN: *Phys. Rev.*, **109**, 193 (1958).

⁽⁹⁾ S. OKUBO, R. E. MARSHAK, E. C. G. SUDARSHAN, W. B. TEUTSCH and S. WEINBERG: *Phys. Rev.*, **112**, 665 (1958).

(13) then gives

$$(18') \quad f_1 = f_e = f_\mu$$

and with (8) and (15), (10) becomes

$$(19) \quad L = f_1[(\bar{p}n) + 0.25(\bar{A}\Xi v)]w + [(f'_1 + f'_3)(\bar{p}\Xi_0) + f'_3(\bar{n}\Xi_-) + 0.25 f_1^2 f_1'^{-1}(\bar{p}A)]_- + \text{h.c.}$$

The conventional β and μ -decay coupling constants g_F are then essentially proportional to f_1^2 while the Fermi coupling constant g_F' relative to non leptonic decays is proportional to

$$0.25(1 + f_3' f_1'^{-1})f_1^2.$$

In the present state of knowledge this gives only a very rough upper limit for $f_3' f_1'^{-1}$, which one may tentatively choose as

$$(20) \quad 0 \leq f_3' f_1'^{-1} \leq 10.$$

Eq. (11) then shows that, with the estimate $y \ll 50\%$ obtained in Section 2'1 (4), the upper limit of the relative amount, y' , of $|\Delta I| \geq \frac{3}{2}$ admixture produced by Lagrangian (19) when the veton mass is finite can be very small: it is less than 10% for $f_3' f_1'^{-1} = 4$, i.e. for $g_F' \sim g_F$.

Similar considerations apply to possible extensions of scheme A that would make it consistent with the conserved current hypothesis (8). If this hypothesis is correct, then supplementary terms are needed in (10) which, in contrast with the previous case, give $|\Delta I| \geq \frac{3}{2}$ admixtures that do not vanish even for an infinite veton mass. The relative amount y' of such admixtures still satisfies, however, relation (11) (where y is the value of y' for $f'_3 = 0$) as is apparent from the fact that (9) leads to a strict $|\Delta I| = \frac{1}{2}$ rule whatever modifications are made to the strangeness-conserving current coupled to w . Under these conditions y' can be made reasonably small provided y is not too large. This, in turn, is presumably the case, also here, whenever graphs of type «a» in Fig. 1 are not negligible as compared to graphs of type «b». It may finally be noticed that y is particularly small if π , Σ and K particles are considered as compounds whose couplings to the Ξ are only moderately strong: the conserved current hypothesis is then satisfied by the simple adjunction of a $(\bar{\Xi}_0 \Xi_-)w$ interaction whose effects, independently of all other considerations, are intrinsically small. The foregoing discussion shows that scheme A can be made to fit all presently established experimental facts by suitable choices of the parameters and with any reasonable choice for the value of the veton mass. It also shows, though merely on the basis of rather qualitative arguments, that it could be adapted to the conserved current hypothesis. It

should be recognized, however, that this latter point is open to discussion for, if the conserved current hypothesis would prove to be strictly correct, scheme A would look somewhat artificial.

Scheme B. — Here we assume that (17) is nearly an equality (which means that decays (16) should be observed in the near future). The leptonic decays of strange particles can then be entirely attributed to the ν -particle acting as intermediate, or, in other words, one may put

$$(21) \quad f'_1 = f_2 = 0.$$

L then takes the simple form given by eq. (9). Immediate consequences of this are that the $|\Delta I|=\frac{1}{2}$ rule is strictly valid (apart from electromagnetic corrections):

- a) for any (finite as well as infinite) value of the veton mass;
- b) also if the conserved current hypothesis is made ($(\bar{p}n)$ in (9) being replaced by J , the strangeness conserving current whose vector part is divergenceless).

Relations (15), (17) and (21) give

$$(22) \quad \begin{cases} f_e = f_\mu, & f'_e \approx f'_\mu, \\ f_1 \approx (f_e^2 + f_e'^2)/f_e, \\ f'_2 \approx f'_3 \approx (f_e^2 + f_e'^2)/4f'_e \end{cases}$$

and the condition that the Fermi coupling constant for non leptonic decay $g'_F \propto f_2'^2$ and the conventional β -decay coupling constant $g_F \propto f_1 f_e$ should be of comparable orders of magnitude sets a further, loose, requirement which can be satisfied in a variety of ways. As an example, we mention here the simple choice: $f_e = f'_e = f_1/2 = 2f'_2$.

Scheme B is attractive in that:

- a) it is strictly consistent with the propositions i), ii), iii) and iv) stated in the introduction, for any veton mass value;
- b) its generalization, so as to incorporate the conserved current hypothesis, is trivial and finally;
- c) it can be easily generalized and given interesting symmetries.

As an example of the latter point, one may mention the following generalization of the non leptonic interaction Lagrangian

$$(23) \quad L = f_1 J w + f_2' [(\bar{N} \cdot E) + (\bar{N} \cdot Z) + (\bar{Y} \cdot E)] v + \text{h. c.},$$

where J is the strangeness-conserving current and Y, Z are the two well-known doublets⁽¹⁰⁾ made of Σ 's and Λ .

On the other hand, scheme B definitely predicts the existence of the decay modes (16), the decay rates for (16) and for the leptonic Λ -decay being both weaker than the values predicted from universality by roughly the same factor.

4. - Observable differences between the veton and schizon theories.

4.1. *Pseudo-schizons*. - Before discussing the similarities and differences between the veton and schizon theories, it is perhaps appropriate to mention very briefly two rather trivial generalizations of the latter. One of them is to rewrite formulae (23) and (24) of Lee and Yang's paper as

$$(24) \quad f_2(\bar{\Lambda}p)w^* + f'_2(\bar{\Lambda}n)w^0 + \text{h. c.},$$

$$(25) \quad f_1(\bar{n}p)w^* - \frac{1}{2}f'_1[(\bar{p}p) - (\bar{n}n)]w^0 + \text{h. c.},$$

with

$$(26) \quad f_1f_2 = f'_1f'_2.$$

The other one is to add to these Lagrangians a term

$$(27) \quad f_3[(\bar{p}\bar{p}) + (\bar{n}n)]w^0 + \text{h. c.}.$$

Both these generalizations can be made simultaneously. Each of them destroys the isovector behaviour of the « schizons » when coupled to the strangeness-conserving current (with the result that they are not true « schizons » any more) but the validity of propositions i), ii) and iii) is identically preserved, for any value of m_w . The proof of this statement (particularly concerning iii)) is elementary: as regards the first generalization ($f_i \neq f'_i$) it relies on the fact that in any $\Delta S = \pm 1$ decays a charged w which is emitted with f_1 is necessarily reabsorbed with f_2 and conversely so that only the product f_1f_2 comes in (and, similarly, the product $f'_1f'_2$ for w^0); as regards the second generalization it is simply adding an isospinor component to a Lagrangian which was already constructed to be an isospinor component. The Lee and Yang scheme so enlarged will be called, for brevity, the pseudo-schizon theory.

4.2. *Experimental predictions with pseudo-schizons*. - These are almost exactly the same as with the schizons. Indeed the only real change is that the relations between $w^\pm$ and w_a^0, w_b^0 decay rates into pions and kaons (eqs. (45) and (47) of ref. (1)) get lost. Also the upper limits on the lepton

(10) M. GELL-MANN: *Phys. Rev.*, **106**, 1296 (1957).

couplings to w^0 have of course to be somewhat modified. Apart from this all the predictions derived in ref. (1) from the schizon theory are valid for the pseudo-schizon theory (including those which stem from the fact that the charged current J is a component of an isovector). This generalization of the Lee and Yang scheme is not therefore of a critical interest for experiments.

4.3. *Experimental predictions with vetons.* — If scheme B (Section 3), is correct Ξ -decays into nucleons and leptons should be observed in the near future. This is an essential difference with the schizon scheme which completely forbids such modes of decay (at least to the 1-st order in weak interactions which are the only relevant ones in such problems). As such experiments are comparatively easy it is not necessary to discuss any further the more subtle differences between the predictions of the schizon theory and of the veton theory in its version « B ». The remainder of this section is thus concerned with observable differences between the schizon theory and the veton theory in its version « A », i.e. when such modes of Ξ -decay are forbidden by both theories.

α) Processes involving no real veton. As long as no (real particle) veton is created, the predictions of the veton scheme A are essentially described by propositions i) to iv) of Section 1, i.e. are substantially the same as those of the schizon theory. The two main differences are

a) that the veton theory strictly forbids any strange particle decay with a lepton pair of total charge zero among the decay products;

b) that, for non-leptonic decays, scheme A predicts some amount of non-electromagnetic $|\Delta I| \geq \frac{3}{2}$ admixture when the veton mass is finite and/or when the conserved current hypothesis is made (as discussed in Section 3).

Also in the class of phenomena with no real vetons are the decays

$$(28) \quad \begin{cases} \Sigma^- \rightarrow \Lambda + e^- + \bar{\nu} \\ \Sigma^+ \rightarrow \Lambda + e^+ + \nu \end{cases}$$

and the inverse μ capture processes

$$(9) \quad \begin{cases} \nu' + n \rightarrow \mu^- + n + \pi^+ \\ \nu' + p \rightarrow \mu^- + p + \pi^0 \\ \bar{\nu}' + p \rightarrow \mu^+ + p + \pi^+ \end{cases}$$

and, more generally,

$$(30) \quad \begin{cases} \nu' + n \rightarrow \mu^- + \Gamma, \\ \bar{\nu}' + p \rightarrow \mu^+ + \Gamma', \end{cases}$$

where Γ and Γ' are complexes of strongly interacting particles with total strangeness zero. All these phenomena proceed through w only and, more precisely, through the term $f(\bar{p}n)w$ in (10), where $(\bar{p}n)$ is a component of an isovector: therefore all the conclusions drawn in ref. (1) for such processes using the schizon theory are also valid in the veton theory, schemes A and B . The detailed experimental study of such processes would therefore offer no clues for a discrimination between the two theories. The same remark holds for the reactions

$$(31) \quad \begin{cases} \bar{v} + n \rightarrow \mu^+ + \Sigma^- & \text{or} & \mu^+ + \Lambda + \pi^- \\ \bar{v} + p \rightarrow \mu^+ + \Sigma^0 & \text{or} & \mu^+ + \Lambda + \pi^0, \end{cases}$$

which proceed through the isospinor components $(\bar{A}\bar{E}_-)$, $(\bar{p}A)$ and therefore obey $|\Delta I| = \frac{1}{2}$ exactly.

β) Processes involving the creation of vetons as real particles (scheme A). If the vetons are created using a beam of v' , or if they are created in a process which involves strongly interacting particles and has $\Delta S = 0$, S being the total strangeness of the initial and final systems of strongly interacting particles, then (18) and (19), respectively, show that only type w vetons are created. If on the other hand these vetons are created in a process which involves strongly interacting particles and has $\Delta S = \pm 1$, both w and v can be created. Examples of such processes are

$$(32) \quad \pi^- + p \rightarrow \Sigma^- + (w^+ \text{ or } v^+),$$

$$(33) \quad K^+ + p \rightarrow p + (w^+ \text{ or } v^+).$$

Finally, if these vetons are created in a similar process with $\Delta S = \pm 2$ such as

$$(34) \quad K^+ + p \rightarrow \Sigma^+ + v^+$$

only v vetons can be created.

On the other hand, the w -decay modes are $e + v$, $\mu + v$, 2π , 3π , $K + \pi$, $K + \gamma$ etc., whereas the v -decay modes are essentially $K + \pi$, $K + \gamma$, $K + 2\pi$ etc. and possibly $K + K$. The branching ratios for the decay of vetons of a given charge are therefore very different according to whether these vetons are all v or a mixture of both, i.e. from what was said above, depending on their mode of production (11). Nothing of that sort takes place in the schizon

(11) We are indebted to Professor YANG for this remark.

theory where there is only one type of charged schizon: this offers therefore in principle a means of discriminating between the schizon and the veton pictures. In practice let us consider for instance the processes with « apparent » change of strangeness (see ref ⁽¹⁾ section 10)

$$\begin{aligned} (35a) & \\ (35b) & \\ (35c) & \\ (35d) & \end{aligned} \quad K^+ + p \rightarrow \Lambda + K^+ + w^+ \rightarrow \begin{cases} \Lambda + K^+ + e^+ + \nu, \\ \Lambda + K^+ + \mu^+ + \nu', \\ \Lambda + K^+ + \pi^+ + \pi^0, \\ \Lambda + K^+ + \pi^+ + \gamma. \end{cases}$$

In the schizon theory the final states can only be obtained from the initial state through the intermediate channel $\Lambda + K^+ + w^+$, as shown in (35) (creation of a real w^+ which subsequently decays). The branching ratios for (35a, b, c, d) are therefore the same as those of

$$\begin{aligned} (36a) & \\ (36b) & \\ (36c) & \\ (36d) & \end{aligned} \quad \nu' + p \rightarrow \mu^- + n + w^+ \rightarrow \begin{cases} \mu^- + n + e^+ + \nu \\ \mu^- + n + \mu^+ + \nu' \\ \mu^- + n + \pi^+ + \pi^0 \\ \mu^- + n + \pi^+ + \gamma \end{cases}$$

In the veton theory, on the other hand, the final states in (35c, d) can also be obtained through

$$\begin{aligned} (37c) & \\ (37d) & \end{aligned} \quad K^- + p \rightarrow \Lambda + \pi^+ + \nu^+ \rightarrow \begin{cases} \Lambda + \pi^+ + K^+ + \pi^0 \\ \Lambda + \pi^+ + K^+ + \gamma. \end{cases}$$

These contributions add to (35c, d) with the result that the net branching ratios for the overall processes described by $K^+ + p \rightarrow$ final states of (35) becomes different from what they are in (36). The experimental discrimination between the two theories consists therefore in this case in picking out the events $K^+ + p \rightarrow$ all final states of (35) (which, if they exist, should be discriminated from ordinary interactions through the change of strangeness they exhibit) and in comparing their relative amounts to the relative amounts of $\nu' + p \rightarrow$ all final states of (36). The same method can be used in pp collisions (replace $K^+ + p$ by $p + p$ and Λ by 2Λ in (35) and (37)).

Another difference between the schizon and veton theories is that apparent processes such as

$$(38) \quad \begin{cases} K^+ + p \rightarrow \Sigma^+ + K^+ + \pi^0 \\ K^+ + p \rightarrow \Sigma^+ + K^+ + \pi^+ \end{cases}$$

which also fall in the class of processes with apparent change of strangeness discussed in ref. (1), Section 10, can happen if the veton theory is correct (the intermediate real state is then $\Sigma^+ + v^+$) but are forbidden in the schizon theory. The same is true for

$$(39) \quad p + p \rightarrow \begin{cases} \Lambda + \Sigma^+ + K^+ + \pi^0 \\ \Lambda + \Sigma^+ + K^0 + \pi^+ \end{cases}$$

Observation of such « apparent » processes would therefore discriminate in favour of the veton theory.

In the third place the veton theory can, as is easily checked, induce no process with apparent $\Delta S = \pm 2$, whereas the schizon theory can, due to the creation of a real w_a^0 (see eq. (52) ref. (1)). Observation of such processes would thus discriminate in favour of the schizon theory: so would, of course, any other conceivable experiment showing that a w^0 exists.

Finally, one may mention the fact that the branching ratio for v and w non leptonic decays are the same as those derived in ref. (1) for the charged schizon. This follows from the fact that $\bar{p}n$, $\bar{\Lambda}E^-$, and $\bar{p}\Lambda$ are components of isotopic vectors or spinors. If $m_v > 2m_K$, v however possesses a decay mode of its own which is

$$v^+ \rightarrow K^+ + K^0.$$

The conclusion of this subsection is that at least five experimental means of discriminating between the schizon and veton theories can be found. These are

- a) a search for Ξ decays into a nucleon and leptons;
- b) a search for leptonic decays with a leptonic pair of total charge zero;
- c) a comparison between the branching ratios of (35) and (36);
- d) a search for some special processes involving « apparent » non conservation of strangeness, such as (38) or (39), and
- e) a search for « apparent » $|\Delta S| = 2$ processes.

5. - Other forms.

One may ask at this stage whether the two versions *A* and *B* above of the veton theory are just two arbitrary examples taken out of a large set of qualitatively different Lagrangians that would all satisfy propositions i) to iv) or whether the theory with charged intermediate bosons only is, apart from various possible choices of the parameters, reasonably unique.

The discussion of this problem is rather involved in the case that the $|\Delta I| = \frac{1}{2}$ rule is required only for infinite veton masses because one has then the supplementary freedom of transforming any given term by means of (4)

as is done for instance in scheme *A*. In spite of this, however, the only alternative to scheme *A* that we found ⁽¹²⁾ is obtained by applying the procedure of Section 2.1 to $(\bar{E}N)(\bar{A}E_-)$ instead of (1). The resulting scheme leads, however, to difficulties as regards the ratio of β -decay to μ -decay coupling constants.

In the case that the $|\Delta I|=\frac{1}{2}$ rule is required to hold exactly for any value of the veton mass as in scheme *B*, the discussion of possible alternatives can be made more rigorous. The $\Delta S=\pm 1$ currents must be isospinor components, because of iii) for leptonic decays; the $\Delta S=0, \pm 2$ currents which combine with these must then have either $I=0$ or $I=1$, because of iii) for non leptonic decays. Being charged, they satisfy moreover to

$$\Delta Q = \Delta I_3 + \frac{1}{2} \Delta U = \pm 1.$$

If $I=0$ this relation gives $\Delta U=\pm 2$: the only possible choice is then $(\bar{E} \cdot N)$, with possible adjunction of $K^* \tau_3 K$. If $I=1$ the component with $I_3=0$ has again $\Delta U=\pm 2$ (as has $(\bar{E} \cdot N)$) but then the component with $I_3=\mp 1$ would have $\Delta Q=0$. This shows that $(\bar{E} \cdot N)$ is essentially the only possible $\Delta S \neq \pm 1$ current that can be used in $|\Delta I|=\pm \frac{1}{2}$ interactions. As for the $\Delta S=\pm 1$ current, it can be any combination of the isospinor components

$$(\bar{p}A); (\bar{A}E_-); (\bar{p}\Sigma_0) + \sqrt{2}(\bar{n}\Sigma_-); -(\bar{\Sigma}_0E_-) + \sqrt{2}(\bar{\Sigma}_+E_0).$$

This gives a qualitative description of all the possible generalizations of scheme *B*.

One of the most attractive among such generalizations is probably (23), which shows that also in the veton theory particles and Lagrangians can be given attractive formal symmetries.

The formal properties of (23) are best described by introducing three abstract spaces I_a, I_b and I_- with the attributions given in Table I. The usual isotopic spin space is then the space orthogonal to the 4-th axis in the 4-space obtained as the direct product of I_a and I_b .

TABLE I. - *Baryons in abstract spaces.*

	I_a	I_b	I_{b3}	I_-	I_{-3}
N, Ξ	$\frac{1}{2}$	0	0 0	$\frac{1}{2}$	$\frac{1}{2} -\frac{1}{2}$
Y, Z	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2} -\frac{1}{2}$	0	0 0

⁽¹²⁾ Except if more than four vetons are introduced.

One can similarly define a 3-space E using I_+ and I_- instead of I_a and I_b . w is then a *scalar* in I_- and a *vector component* in I_+ , while v is a *scalar* in I_a and a *vector component* in E . As regards strong interactions, only the invariance in I space is postulated.

6. — Conclusions.

It has been shown that the veton theory can receive at least two qualitatively different formulations. Both of them are in agreement with present experimental knowledge. Both of them lead to predictions which are in some respects different from those of the schizon theory. For one of them (scheme A) these observable differences, which are described in Section 4, bear on the results of some of the experiments, suggested by LEE and YANG in order to test the validity of the intermediate boson assumption. This first formulation (scheme A), although it is not as «natural» as the schizon theory (cf. Section 3), is therefore a possible alternative to it, to which the absence of any observed neutral leptonic current effects (proposition iv) in Section 1) gives some preliminary support and which could be proved or disproved by experiment. The other formulation (scheme B) differs from the schizon theory in that it definitely predicts the $\Delta S = 2$ leptonic decay of the Ξ (reactions (16)) which is completely forbidden in the schizon theory as well as in scheme A . If scheme A is correct, these decays should occur with a decay rate proportional not to the square of the β -decay coupling constant but to the square of the, weaker, Λ leptonic decay coupling constant: their branching ratio against normal Ξ -decay should then be ⁽¹³⁾ 1:20 to 1:50. Scheme B is on the other hand much more «natural» from a theoretical point of view than scheme A (see Sections 3 and 5) and, indeed, can be compared with the schizon theory in that respect, with of course the supplementary advantage that it implies proposition iv) of Section 1 on the absence of neutral leptonic current effects. For these reasons an experimental study of the leptonic decay of the Ξ , and a particular search for processes (16), would be of considerable interest for the theory.

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⁽¹³⁾ We use the «Table of the leptonic decay rates of the hyperon» by Y. YAMAGUCHI: *CERN report* No. 59-18 (1959).

RIASSUNTO (*)

Le regole $|\Delta S|=1$ per il decadimento non leptónico e $|\Delta I|=\frac{1}{2}$ sono giustificate da una teoria in cui le interazioni deboli sono dovute a bosoni intermedi dotati di carica, che non hanno un corrispondente neutro. I decadimenti leptónici delle particelle strane in cui la carica totale dei leptoni è zero, sono quindi proibiti, d'accordo con gli esperimenti. Si discutono le differenze osservabili con la predizione della teoria di Lee ed Yang. Sebbene il modo di decadimento leptónico con $\Delta S=2$ delle particelle delle cascate possa anche essere proibito, per una opportuna scelta dei parametri, la teoria dà tuttavia alcuni argomenti a favore della sua esistenza, con una costante di accoppiamento uguale a quella del modo di decadimento leptónico del Λ , cioè con una velocità di decadimento circa venti volte più piccola della velocità del normale decadimento Ξ .

(*) Traduzione a cura della Redazione.