EPRINCE-RINGUET - Je suis d'accord que l'argument de Peters est très fort. Il faut cependent faire très attention aux conditions experimentales. Certaines désintégrations de κ parmi les 60 observées à Bristol, ont un primaire court. S'ils avaient eu à leur extrémité une étoile nucléaire, on n'aurait pas pu les identifier (ne pouvant directement mesurer leur masse), tandis que chez Peters, ces primaires ne sont jamais courts puisqu'il utilise des émulsions pelées; au contraire, le méson tau se voit tout de suite, même si son primaire est court.

ROSSI - This argument speaks against $\kappa \cong \tau$ rather than against $\chi \cong \kappa$.

MICHEL - What is the mass of the χ assuming a decay into $\pi + \gamma$.

ROSSI - The average value of the emission energy is 116.6 ± 6 Mev. The tau-mass corresponds to 125 Mev.

J - 3 ABSOLUTE SELECTION RULES FOR DECAY PROCESSES.

L. MICHEL

Most of you are quite suspicious against theorists and prefer, to their advice, the answer of Nature. You are right. However, a physicist cannot work without the help of the best proved theoretical laws : no physicist would present a decay scheme where the momentum, the energy or the electric charge were not conserved.

Taking into account the stability of nuclei, we have also to assume the conservation of the number of nucleons. If antinucleons exist, this must be understood as the conservation of the "difference between the number of nucleons and of antinucleons". If the V_1 particles, as seems well proved, are made out of nucleons, they have to be counted in this conservation law.

The conservation of angular momentum, cannot be seperated from the conservation of momentum and energy. These conservation laws can be deduced from classical physics.

But a still better approach is to start directly from the special relativity principle, and the fundamental axioms of quantum mechanics. Another non classical conservation law is then introduced : the conservation of parity. Furthermore one obtains the quantification of angular momentum. The best study along this line is due to Wigner[1]. First we give his results on the classification of particles from the point of view of their Lorentz invariance.

1. CLASSIFICATION OF PARTICLES.

Let us call particle any isolated physical system, and spin its angular momentum (e.g. atom, nucleus, α-particle, τ-particle, π-meson, proton, and so on). From the point of view of Lorentz invariance, the particles are characterized by their mass m, spin S, and eventually intrinsic parity. Their state is characterized by the momentum and the polarization (n linearly independent states).

TABLE I

Mass	Spin	Intrinsic Parity	Number of linearly independent states of polarization.
$m \neq 0$	2S integer ≥ 0	Yes	2S + I
$m = 0$	$S = 0$	Yes	I
$m = 0$	2S integer > 0	No	2
$m = 0$	Ξ or Ξ'	Yes	∞

The concept parity and intrinsic parity are very subtle [1,2] and weaker than is generally believed (from atomic physics). We shall not go here into details on this point.

There are two possible intrinsic parities for integer spin, $m \neq 0$, particles : $\varepsilon = \pm I$; the particles with $\varepsilon =$ -I are called pseudo (ex : pi-mesons are pseudoscalar $S_\pi = 0$ and $\varepsilon_\pi = -I$)

The particles Ξ and Ξ' have been considered by Wigner only. Their existence is possible. They are included in this discussion.

As an illustration of the table, vector meson : $m \neq 0$, $S = 1$, $\varepsilon = 1$, $n = 3$ (one longitudinal, 2 transversal states) whereas for a photon : $m_\gamma = 0$, $S_\gamma = 1$, no intrinsic parity and only $n = 2$ states of polarization (no longitudinal state).

The question "what particles are elementary ?" is completely irrelevant to our considerations. Sometimes physicists consider two different "particles" (in the meaning given above) as two states of the same particle : this is presently a matter of convention. We shall see that other numbers than m, S, ε, can be necessary to characterize the particles. Nevertheless, if one observes two different types of decay, they can correspond to the same particle only if m, S, ε, are the same ; moreover the apparent lifetime of the two processes must be the same.

2. LIST OF ABSOLUTE SELECTION RULES FOR DECAY.

A - Due to angular momentum conservation

1 forbidden if the total number of half-integer spin particles is odd (evident)

$m_B = m_C = 0$ and $S_A < (S_B - S_C)$

2 $A \rightarrow B + C$ forbidden if $m_C = 0$ and $S_A + S_B < S_C$.

3 $A \rightarrow 2\,C$ forbidden if $m_C = 0$ and S_A is odd and $< 2\,S_C$

4 $A \rightarrow 2\,B$ forbidden if $S_B = 0$ and S_A is odd.

B - Due to parity conservation.

5 $A \rightarrow B + C$, forbidden if two of S_A, S_B, $S_C = 0$ and $\varepsilon_A \varepsilon_B \varepsilon_C = -1$

on $A+B \rightleftarrows C+D$

6 $A \to B + C + D$, forbidden if $S_A = S_B = S_C = S_D = 0$ and $\varepsilon_A \varepsilon_B \varepsilon_C \varepsilon_D = -1$

7 $A \to 2C$, forbidden if $m_C = 0$, S_A odd, $\varepsilon_A = +1$ when S_C integer

$\varepsilon_A = ?$ when S_C half-integer

8 $A \to 2B$ forbidden if $S_B = 1/2$, $S_A =$ [illegible], $\varepsilon_A = ?$

Note : In 7 and 8 we write $\varepsilon_A = ?$ because it depends on the intrinsic parities of half-integer spin particles. The ? is either 1 or -1 (independent of the nature[2] of the half-integer spin particle), but this value is not yet known. It will be +1 if neutrinos are proved to be Majorana[4] particles (no antineutrinos). Several cases of this list are well-known (2 : the transitions $\bar{0} \leftrightarrow 0$ are forbidden ; 3: $\pi^0 \to 2\gamma$ excludes spin 1 for π^0). It does not seem that the complete list is generally known [5,6].

3. CHARGE CONJUGATION. -

Up to now , nobody has been able to make a theory describing a charged particle (or a neutral particle with a magnetic moment) without an antiparticle. Moreover there is a complete symmetry between the two "charge conjugate states" of such a particle.
Some neutral particles (as γ, π^0) have no antiparticles. We shall call them strictly neutral. For neutrinos, it is not yet known whether there are "neutrinos" and "antineutrinos" or only "strictly neutral" neutrinos (all neutrinos identical); in the last case they can be described by the Majorana [4] theory.

Let us call C the operation of "charge conjugation", i.e. the transformation of the two "charge conjugate states" of a particle into each other. Strictly neutral particles are changed into themselves by C. All present theories are invariant under charge conjugation : that means no observable change in the universe if it is transformed by C. It is why physicists believe in the existence of antiprotons and antineutrons. They may be wrong, but, since no theory without charge conjugation has been found, it is interesting to know its consequences. Here we shall be interested only in those leading to absolute selection rules[7] for decays. This rule appears for eigen states of C. Their eigen value is a new quantum number $c = \pm 1$ "the charge conjugation parity".

The value of c for one photon[8] is $c_\gamma = -1$; for a state of n photons, $c = (-1)^n$. Since we know $\pi^0 \to 2\gamma$, we deduce $c_{\pi^0} = 1$. This c is well defined for all states containing only strictly neutral particles. Among states which can occur as secondary of the decay of one particle, those containing only one particle and its antiparticle (as $\pi^+ + \pi^-$, $\mu^+ + \mu^-$ or $e^+ + e^-$) have well defined c in the three following cases[9]:

1°) The total angular momentum $J = 0$; then $c = -1$ is not possible.

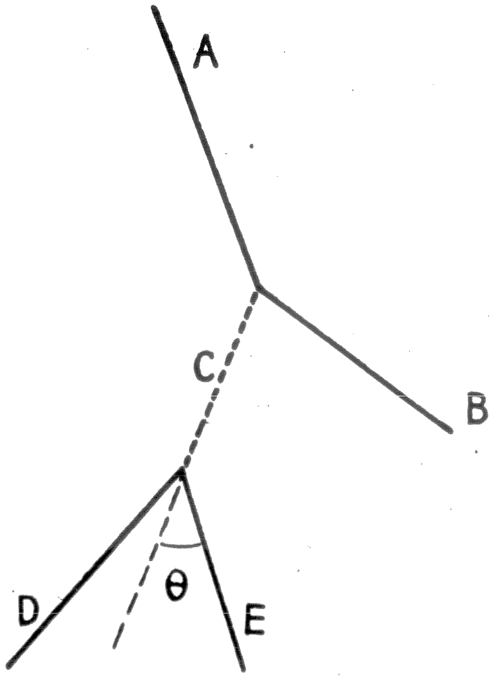
2°) The "charge conjugate" particles have spin 0 (as $\pi^+ + \pi^-$); then $c = -(-1)^J$ is not possible.

3°) The "charge conjugate" particles have spin 1/2 (as $e^+ + e^-$), and the "intrinsic parity" of the state is $\varepsilon = +1$ (non pseudo); then $c = -(-1)^J$ is not possible.

From that, and the values of c for strictly neutral particles, one can easily deduce the complete list of absolute selection rules for decays, due to charge conjugation (i.e., conservation of the "charge conjugation 'parity" c).

4. VALUES OF ABSOLUTE SELECTION RULES.

They are fundamental. It seems very difficult for a physicist to reject those absolute selection rules. Those due to angular momentum conservation have the same foundation as energy and momentum conservation (invariance under the connected group of Lorentz, inhomogenous transformations). If you reject the other, you know what hypotheses you are rejecting. Note that only c (not the angular momentum or the parity) is conserved in reaction involving "virtual particles" (in perturbation theory). This allows for instance to explain why $\pi^0 \to 2\gamma$ and to a smaller degree $\pi^0 \to \gamma + e^+ + e^-$ are the more probable decay schemes of π^0 and that the distribution of secondary momenta in $\pi^0 \to \gamma + e^+ + e^-$ is far from statistical.



Outside absolute selection rules the conservation laws predict also a number of useful (and fundamental) results. Here is the simplest example of angular correltation into two successive decays in flight as an indication of the possibilities :

Let us suppose :

$$S_A = S_B = S_D = S_E = 0,$$
$$S_C = 1$$

Since $A \to B + C$ would be forbidden if C were a photon, C is emitted in a longitudinal state. Since C is polarized the distribution of momenta of D and E in the center of mass system is not isotropic ; in this example,

$$P(\theta^*) \sim \cos^2\theta^* .$$

5. WEAK SELECTION RULES

Other quantum numbers can be attached to particles. For instance (in the hypothesis of "charge independence"), a particle with isotopic spin T has 2T+1 states. It seems that T is a good quantum number for nuclei when one neglects $m_n - m_p$ and electromagnetic interactions. Therefore T conservation can lead only to weak selection rules. Nucleons have T = 1/2, $pi^{\pm}$ and pi^{0} mesons are 3 states of the "same" particle with T = 1. The combination of T-conservation and charge conjugation can lead to new weak selection r rules. It has been shown[9] that they can be found by the conservation of "isotopic parity"t. For integer spin mesons, $t = c\,(-1)^T$ where c has already been defined for neutral particles :

e.g. $c_{\pi^0} = 1$, $T_{\pi} = 1$, therefore $t_{\pi} = -1$ (π-mesons are polar vector in isotopic space[10]).

However it is not known whether isotopic spin is a good quantum number for the new mesons found in cosmic Rays. A weaker hypothesis is that of "charge symmetry", expression very badly framed, to say that there is a complete symmetry between protons and neutrons when one neglects $m_p - m_n$ and electromagnetic interactions. I have not seen during all the conference a physicist not making(at least implicitly) this hypothesis. If you take it in account with charge conjugation you will find new selection rules[11]. To find them, you can attach to neutral mesons a "charge symmetry parity" $\omega = \pm 1$ (independent of m, S, ε, c). For charged mesons the "charge symmetry parity" will be noted ϖ. The relative sign ω/ϖ for two particles has no signification, but a product of an even number of ϖ is of the nature of ω (only an even number of charged particles are involved in a reaction) The ϖ of a charged meson is function of the c (here taken as = -c) of the "corresponding" neutral meson i.e., with same S, ε and interactions. This "corresponding" neutral meson may not exist. If it exists (as π^0 for $\pi^{\pm}$), this does not ensure "charge independence". However ω and ϖ are chosen here so that $\omega = \varpi = t$ if (for "corresponding" mesons) the more special hypothesis of "charge independence" is also a good approximation. Reactions slowed by T or t conservation would be those slowed by ω, ϖ conservation and some more due to the fact that for "charge independence" corresponding mesons are then states of the "same" particle.

6. EXAMPLE OF APPLICATION

Prof. Rossi has just emphasised the striking similarity of masses of θ° and $\tau^{\pm}$. The table 1 gives in a condensed form the selection rules for the different possible decay schemes of these particles.

Columns indicate S, ε, c, ω, of θ° and S, ε, ϖ of $\tau^{\pm}$. When a decay scheme is forbidden, the letter in the corresponding line indicates the nature of the forbidness.

Table 2. SELECTION RULES FOR THE θ° AND $\tau^\pm$ DECAY SCHEMES

S	0								1								even ≥ 2								odd ≥ 3							
ε	+				−				+				−				+				−				+				−			
c	+		−		+		−		+		−		+		−		+		−		+		−		+		−		+		−	
ω	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−
$\theta^\circ \to 2\gamma$			C	C			C	C	A′	A′	A′	A′	A′	A′	A′	A′			C	C			C	C	P′	P′	P′	P′			C	C
$\theta^\circ \to \pi^\circ + \gamma$	A	A	A	A	A	A	A	A	C	C			C	C			C	C			C	C			C	C			C	C		
$\theta^\circ \to 2\pi^\circ$		ω	C	C	P	P	P	P	A′	A′	A′	A′	A′	A′	A′	A′		ω	C	C	P	P	P	P	A′	A′	A′	A′	A′	A′	A′	A′
▨ $\theta^\circ \to \pi^+ + \pi^-$		ω	C′	C′	P	P	P	P	C′	C′		ω	P	P	P	P		ω	C′	C′	P	P	P	P	C′	C′		ω	P	P	P	P
$\theta^\circ \to \mu^+ + \mu^-$			C′	C′			C′	C′	C′	C′									C′	C′					C′	C′						
$\theta^\circ \to e^+ + e^-$			C′	C′			C′	C′	C′	C′									C′	C′					C′	C′						
? $\theta^\circ \to 2\nu$			C′	C′			C′	C′	P′	P′	P′	P′			C′	C′			C′	C′			C′	C′	P′	P′	P′	P′			C′	C′
$\theta^\circ \to 3\pi^\circ$	P	P	P	P	ω		C	C	ω		C	C	ω		C	C	ω		C	C	ω		C	C	ω		C	C	ω		C	C
$\theta^\circ \to 2\pi^\circ + \gamma$	C	C			C	C			C	C			C	C			C	C			C	C			C	C			C	C		
$\theta^\circ \to \pi^\circ + 2\gamma$			C	C			C	C			C	C			C	C			C	C			C	C			C	C			C	C
$\theta^\circ \to 3\gamma$	C	C			C	C			C	C			C	C			C	C			C	C			C	C			C	C		
☐ $\theta^\circ \to \pi^+ + \pi^- + \pi^\circ$	P	P	P	P	ω		ω		ω		ω		ω		ω		ω		ω		ω		ω		ω		ω		ω		ω	
Charge indépendance	T			T	T			T	T			T	T			T	T			T	T			T	T			T	T			T
Usual Theories							☒	☒	☒	☒							☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒	☒

S	0				1				even ≥ 2				odd ≥ 3			
ε	+		−		+		−		+		−		+		−	
Θ	−	+	−	+	−	+	−	+	−	+	−	+	−	+	−	+
☐ $\tau^\pm \to \pi^\pm + \gamma$	A	A	A	A												
☐ $\tau^\pm \to \pi^\pm + \pi^\circ$	Θ	T′	P	P	Θ		P	P	Θ	T′	P	P	Θ		P	P
▨ $\tau^\pm \to 2\pi^\pm + \pi^\mp$	P	P		Θ		Θ		Θ		Θ		Θ		Θ		Θ
☐ $\tau^\pm \to \pi^\pm + 2\pi^\circ$	P	P		Θ		Θ		Θ		Θ		Θ		Θ		Θ

A means forbidden by momentum conservation
P means forbidden by parity conservation
C means forbidden by charge conjugation.

Dotted letters $\dot{\omega}, \dot{\varpi}$ or $\dot{t}, \dot{T}$ indicate that the reaction is slowed by "charged symmetry" or "charge independence". However, only one letter is indicated for each case, the priority order being $A > P > C > \omega$ or $\varpi > t$ or T. The " ' " indicates that one has to take into account the fact that all secondaries are states of the "same" particle.
For the line $\theta^{\circ} \to 2\nu$ the $\rightarrow$ indicates its validity only for Majorana[4] neutrinos.
Between the two sets of schemes the T, on the line "charge independence", indicates the columns excluded for θ° in the hypothesis that θ° and $\tau^{\pm}$ are states of a particle of isotopic spin $T = 1$ (as π° and $\pi^{\pm}$ are).

The X's on the line "Usual theories" indicate the cases not usually considered by theorists[12].

But presently it seems essential, when we discuss the nature of new particles, not to restrict ourselves to the only cases that theorists use to treat by numerical computations!
We recall here that :

		m	S	ε	C	ω	ϖ
for	γ	0	1	no	-	no	
for	π°	$\neq 0$	0	-	+	-	
for	$\pi^{\pm}$	$\neq 0$	0	-	no		-

and $\omega_{\pi^{\circ}} = \varpi_{\pi^{\pm}} = t_{\pi}$

▨ indicates the schemes experimantally identified with certainty, ☐ those which may have been observed. Decays into four particles or more are less probable and therefore not studied. Of course, considerations of statistical available phase space and, chiefly, of strength of coupling must also be taken into account for deciding the relative probalities of the different allowed schemes. For instance to replace a $\pi^{\pm}$ by $\mu^{\pm} + \nu$ or a π° by $\mu^{\pm} + e^{\mp}$ in a decay scheme, gives certainly a much slower reaction.
Decay schemes into 2 or 3 particles not studied in the Table 2, are allowed in all cases. (Main example $\tau^{\pm} \to \pi^{\pm} + 2\gamma$).

From the column $S_{\theta} = S_{\tau} = 2$, $\varepsilon_{\theta} = \varepsilon_{\tau} = 1$ $C_{\theta} = -\varpi_{\tau} = 1$ $\omega_{\theta} = 1$

of table 2 one can note that the experimental data ;
($\theta^{\circ} \to \pi^{+} + \pi^{-}$ and $\tau^{\pm} \to 2\pi^{\pm} + \pi^{\mp}$ are the most frequently observed decay schemes of these two particles) is compatible with the hypothesis : θ° and $\tau^{\pm}$ are "corresponding particles". (but, of course, isotopic spin is not a good quantum number in that case).

Notes.

1. Wigner, Ann. Math. 40,101, 1939.
2. Wick, Wightmann, Wigner, Phys. Rev., 88, 101, 1952.
3. Physicicists sometimes say also even ($\eta = 1$) and odd ($\eta = -1$) for intrinsic parities. Then $\eta = \varepsilon (-1)^S$.
4. Majorana, Nuovo Cim. 14, 171, 1937.
5. See for instance Peaslee, Helv. Phys. Acta, 23, 845, 1950.
6. The question of the decay of zero mass particle is not treated here. The complete list is proved in Michel, 2nd thesis, Sorbonne 1953: to be published. However its completeness can be proved only from the not yet published work of Gårding and Wightman. These authors have solved the problem of the reduction (into irreducible representations) of the product of two representations of the inhomogenuous Lorentz group. I thank them very much for communication of their results prior publication.
7. They are due to the contributions of Furry, Phys. Rev. 1125, 1937; Wolfenstein and Ravenhall, Phys. Rev. 88, 279, 1952 and ref.[9].
8. Indeed, the theory is invariant under C, so is the interaction term $A^\mu j_\mu$. But the current j_μ is changed of sign by C, so is the photon field A^μ.
9. Michel, Nuovo Cim. 10, 319, 1953.
10. Nucleons have no "intrinsic isotopic parity".
11. They are due to the contributions of Furry[7], Fukuda and Miyamoto : Progr. Theor. Phys. 4. 389, 1949, and Michel[12]. Better proofs were given by Pais and Jost, Phys. Rev. 87, 871, 1952.
    For systematic study of selection rules (outside spontaneous decay) due to charge symmetry only, see Kroll and Foldy, Phys, Rev. 88 1177. 1952; due to charge symmetry and conjugation : Michel[9].
12. Michel, chapter 3 of Progress in Cosmic Ray Physics (North Holland Publishing Co., Amsterdam 1952).
13. For the usual cases : spin 0 or spin 1 mesons, Kemmer[14] Couplings, I have already published the equivalent of Table 2 in ref 12, page 154 and 158.
14. Kemmer, Proc. Roy. Soc. A. 166, 127, 1938.

BHABHA. It is true that all this comes out on the basis of the present theory of special relativity.
The invariance under the Lorentz group consists of three different things : the invariance under rotations, the invariance under special reflections and the invariance

under reflection of the time axis. Now this last parity which Dr. Michel talked about, the charge conjugation parity is intimately connected with the reflections of the time axis, and, as no one has yet performed an experiment with reversal of the time, I would hesitate to say that this is something which experimantally is necessary. But I would say in support of what he has said, that I have tried for some time to work on the relativistic wave equations, I started only from the assumption of having rotation and space reflection invariance. But you can then show that within the frame of present quantum mechanics, you also automatically get invariance for time reflections, and therefore this last type of parity. I do not think you can say it is experimentally compelling, it may be that if you get away fundamentally from the present framework, you will get away from that last parity; but still, it would be a very radical departure.

J - 4

ON THE PRODUCTION OF K-MESONS

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Reported by U. Haber-Schaim

I should like to report on an attempt to calculate the excitation function of K-particles above their threshold. The large number of K-particles produced in nuclear disintegrations above 5 Bev suggests that these particles have strong interaction with nuclear matter.

We applied Fermi's theory of meson production (1) originally dealing with pi-meson to the case of K-particles. According to this theory the pi-mesons are produced in a small volume :

$$\Omega_\pi = \frac{4\pi}{3} r_\pi^3$$

where $r_\pi = \hbar/m_\pi c$ is the Yakuwa range associated with the pi-meson field of mass m_π. If it is assumed that the K-particle interacts with the nucleon through a K-meson field which is independent of the pi-meson field, the K-particles are produced in a volume :

$$\Omega_K = \frac{4\pi}{3} r_K^3$$

where $r_K = \hbar/m_K c$ is the range associated with a K-peson of mass M_K-