ln$s$, which must be expected to require large ln$t$ (time in years).

I am grateful to F. E. Low for an enjoyable discussion on the significance of this way of looking at multiparticle production. My own understanding of the subject owes much to discussions over a period of years with J. D. Bjorken, L. Castillejo, F. Cooper, E. L. Feinberg, K. Gottfried, and V. N. Gribov.

[1]L. D. Landau, Izv. Akad. Nauk SSSR, Ser. Fiz. 17, 51 (1953); S. Z. Belenkii and L. D. Landau, Usp. Fiz. Nauk 56, 309 (1955). For a review see F. Cooper, in *Particles and Fields—1974*, AIP Conference Proceedings No. 23, edited by C. E. Carlson (American Institute of Physics, New York, 1975), p. 499.

[2]D. Amati, S. Fubini, and A. Stanghellini, Nuovo Cimento 26, 896 (1962). The time-order results for the multiperipheral parton model were reviewed by J. D. Bjorken, SLAC Report No. 167, 1973 (unpublished) p. 1; O. V. Kancheli, Pis'ma Zh. Eksp. Teor. Fiz. 18, 465 (1973) [JETP Lett. 18, 274 (1973)]; J. Kogut and L. Susskind, Phys. Rep. 8C, 75 (1973).

[3]A. S. Goldhaber, Phys. Rev. Lett. 33, 47 (1974).

[4]F. E. Low, Massachusetts Institute of Technology

Report No. CTP 438 (to be published).

[5]This contradicts the statistical model of E. Fermi, Progr. Theor. Phys. 5, 570 (1950), and Phys. Rev. 81, 683 (1951). Fermi was refuted by I. Ya. Pomeranchuk, Dokl. Akad. Sci. SSSR 78, 889 (1951), who argued that production cannot occur instantly. See E. L. Feinberg, Phys. Rep. 5C, 237 (1972).

[6]In the original hydrodynamic model, T increases with the collision energy, but in later, softened versions, T is fixed; see Ref. 1. The suggestion that any local field theory may lead to an initial phase of the production process characterized by a transport equation (i.e., generalized hydrodynamics) has been developed by P. Carruthers and F. Zachariasen, in *Particles and Fields—1974*, AIP Conference Proceedings No. 23, edited by C. E. Carlson (American Institute of Physics, New York, 1975), p. 481.

[7]The way that the initial collision and later particle appearances are defined varies with the model, but for a given definition these events may always be fixed with the help of weak probes. Note that while each observer is at rest in some inertial frame, the matter which eventually forms a given final particle is not necessarily in free motion during the formation process. In fact, this matter is quite likely to be accelerated while it is accumulated.

[8]J. Benecke, T. T. Chou, C. N. Yang, and E. Yen, Phys. Rev. 188, 2159 (1969); R. P. Feyman, Phys. Rev. Lett. 23, 1415 (1969).

[9]J. Koplik and A. H. Mueller, to be published.

[10]A. Dar and J. Vary, Phys. Rev. D 6, 2412 (1972).

[11]K. Gottfried, Phys. Rev. Lett. 32, 957 (1974).

[12]P. M. Fishbane and J. S. Trefil, Phys. Lett. 51B, 139 (1974).

Search for Charmed Particles

Y. Iwasaki
Department of Physics, University of Tsukuba, Ibaraki, 300-31, Japan
(Received 7 July 1975)

It is suggested that the channels $\Sigma^+ K^-$, $\Sigma^- \pi^+$, and $\Xi^- \pi^+$ in the mass region 2.3–2.5 GeV, but not the channels $\pi^\pm K^\mp$ and $p K^-$, be examined in a search for neutral charmed particles.

Although there are some indications of the existence of charmed particles[1] in emulsion-chamber experiments (both in a cosmic-ray experiment[2] and in an accelerator experiment[3]), there are also negative results[4] in the search for charmed particles as resonances. Since the charm scheme is promising with respect to both understanding[5] the suppression of the strangeness-changing semileptonic processes and interpreting the ψ particles[6] as hidden charm states, it is very urgent to establish the existence or the nonexistence of charmed particles.

Possibly the easiest way to search for charmed particles as resonances is to look into the invariant-mass plot of the two charged particles which might be the decay product of the parent neutral charmed particle. In this Letter I investigate in which channels one may expect neutral resonances and point out that to search for neutral charmed particles it is appropriate to look into the channels $\Sigma^+ K^-$, $\Sigma^- \pi^+$, and $\Xi^- \pi^+$, but not $\pi^\pm K^\mp$ and $p K^-$. I further conjecture their invariant masses

to be at 2.3–2.5 GeV.

Since the charmed pseudoscalar mesons are probably the lowest mass states among the charmed particles, they will be stable against the strong interaction and they will be very sharp resonances. So it is natural to search for the charmed pseudoscalar, D^0 ($c\bar{u}$), which could decay to $\pi^{\pm}K^{\mp}$ if we take into account only the quantum numbers. However, as I have pointed out in a recent article,[7] the main two-body decay of the D^0 meson is $\bar{K}^0\eta$ if the $45\oplus45^*$ parts of the effective Hamiltonian are suppressed. If this is the case, it is not appropriate to look into the channels of two charged particles (i.e., $\pi^{\pm}K^{\mp}$) to search for the D^0 meson.

The next candidate is the vector meson D^{0*} ($c\bar{u}$). Since the D^{0*} meson may be heavier than the D^0 meson, it will decay via the electromagnetic interaction or the strong interaction if the Q value is large enough. So it is not appropriate again to look into the channels of two charged particles to search for the D^{0*} meson.

Now I turn to the case of charmed baryons. I assign the $\frac{1}{2}^+$ baryon to $\underline{20}'$ (mixed symmetry), while the $\frac{3}{2}^+$ baryon is assigned to $\underline{20}$ (completely symmetric), as usual. Whether they decay via the strong interaction depends on their masses. To estimate their masses, I use the result of the experiment[8] by Cazzoli et al. That is, I assume that the mass of the lowest charmed baryon is about 2.4 GeV. I will present the justification of this assumption later.

Let us assume an SU(4) symmetry breaking of the form

$$H' = \alpha_3 T_3{}^3 + \alpha_4 T_4{}^4, \tag{1}$$

postulating that $x \equiv \alpha_4/\alpha_3$ is common to both the $\frac{1}{2}^+$ and the $\frac{3}{2}^+$ multiplets. For example, taking $x = 8.05$ and using the linear mass formula, we obtain the results shown in Table I. Included is the predicted mass for the vector mesons also, obtained from the linear mass formula. In this case we obtain $x = 9.7$ from the mass of $\psi(3.1)$. On the other hand, if we use the quadratic mass formula, we obtain $x = 20.7$.[9] The value $x = 9.7$ is nearly equal to the value $x = 8.05$, while the value $x = 20.7$ is quite different. Thus I suggest that the linear mass formula is better than the quadratic mass formula even for the vector meson (and maybe also for the pseudoscalar meson). If that is the case, the mixing angles, for example, should be calculated using the linear mass formula.

From Table I, we can see that the SU(3) $\underline{3}^*$ mul-

TABLE I. Predicted masses of the charmed particles based on the SU(4) linear mass formula. We use the masses of $\psi(3.1)$ and $\Delta_c^{++}(I=1, Y=0, C=1)$ as input.

SU(3) representation	Quantum numbers (I, Y, C)	Predicted mass (GeV)
Vector mesons		
$\underline{3}$ (D^{+*}, D^{0*})	$(\frac{1}{2}, -1, 1)$	1.9
F^{+*}	$(0, 0, 1)$	2.05
$\frac{1}{2}^+$ baryons		
$\underline{3}^*$ $(B_c{}^+, B_c{}^0)$	$(\frac{1}{2}, -1, 1)$	2.35
$B_c{}^+$	$(0, 0, 1)$	2.6
$\underline{6}$ $(B_c{}^{++}, B_c{}^+, B_c{}^0)$	$(1, 0, 1)$	3.0
$(B_c{}^+, B_c{}^0)$	$(\frac{1}{2}, -1, 1)$	3.1
$B_c{}^0$	$(0, -2, 1)$	3.35
$\underline{3}$ $(B_c{}^{++}, B_c{}^+)$	$(\frac{1}{2}, -1, 2)$	4.0
$B_c{}^+$	$(0, -2, 2)$	4.25
$\frac{3}{2}^+$ baryons		
$\underline{6}$ $(\Delta_c{}^{++}, \Delta_c{}^+, \Delta_c{}^0)$	$(1, 0, 1)$	2.4
$(\Delta_c{}^+, \Delta_c{}^0)$	$(\frac{1}{2}, -1, 1)$	2.55
$\Delta_c{}^0$	$(0, -2, 1)$	2.7
$\underline{3}$ $(\Delta_c{}^{++}, \Delta_c{}^+)$	$(\frac{1}{2}, -1, 2)$	3.6
$\Delta_c{}^+$	$(0, -2, 2)$	3.7
$\underline{1}$ $\Delta_c{}^{++}$	$(0, -2, 3)$	4.7

tiplet of $\frac{1}{2}^+$ baryons and all the charmed $\frac{3}{2}^+$ multiplets ($C = 1$, $C = 2$, and $C = 3$) are stable against the strong interaction. The SU(3) $\underline{6}$ multiplet of $\frac{1}{2}^+$ baryons is unstable against the strong interaction, while the SU(3) $\underline{3}$ multiplet ($C = 2$) may or may not be metastable, since the predicted masses are near the threshold. If we assume that the charmed particle produced in the experiment of Cazzoli et al. is a doubly charged baryon, it should be a $\frac{3}{2}^+$ baryon, since a doubly charged $\frac{1}{2}^+$ baryon should exist at a higher mass level and should be unstable against the strong interaction.

Let us investigate the two-body decays [a $\frac{1}{2}^+$ baryon and a pseudoscalar meson] of these metastable particles. We are especially interested in the two-charged-particle decays of the neutral particles ($C = 1$). If we assume SU(4) $\underline{20}$ dominance[10] of the current-current product, we obtain the following selection rules:

$$\Delta_c(\tfrac{3}{2}^+, I=1, Y=0, C=1) \nrightarrow pK^-, \Sigma^+\pi^-, \Xi^-K^+,$$
$$\Delta_c(\tfrac{3}{2}^+, I=1/2, Y=-1, C=1) \nrightarrow \Sigma^+K^-, \tag{2}$$

using the conservation of the d-c spin [which corresponds to the u-d spin (I spin), the d-s spin (U spin), and the u-s spin (V spin)]. Thus the al-

lowed (two-charged-particle) decays are

$$B_c{}^0(\tfrac{1}{2}{}^+, I=\tfrac{1}{2}, Y=-1, C=1) \to \Xi^-\pi^+, \Sigma^+K^-,$$

$$\Lambda_c{}^0(\tfrac{3}{2}{}^+, I=1, Y=0, C=1) \to \Sigma^-\pi^+,$$

$$\Lambda_c{}^0(\tfrac{3}{2}{}^+, I=\tfrac{1}{2}, Y=-1, C=1) \to \Xi^-\pi^+,$$ (3)

$$\Lambda_c{}^0(\tfrac{3}{2}{}^+, I=0, Y=-2, C=1) \to X.$$

Here and hereafter we take into account only the term proportional to $\cos^2\theta$ (θ is the Cabibbo angle). The above selection rules are derived in the case of SU(4) symmetry. If we take into account the SU(4) symmetry breaking which is large, the selection rules do not generally hold. However, if the $\underline{45} \oplus \underline{45}{}^*$ parts of the effective Hamiltonian are suppressed compared with the $\underline{20}$ part after taking the effect of the SU(4) symmetry breaking as a perturbation as in Ref. 7, the selection rules still hold. It should be noted that the decay to pK^- is forbidden under the selection rules. Under the same assumption, the decay $D^0 \to \pi^\pm K^\mp$ is suppressed.[7]

Thus to search for charmed particles we should look into the channels $\Xi^-\pi^+$, Σ^+K^-, and $\Sigma^-\pi^+$, but not the channels pK^-, $\Sigma^+\pi^-$, and Ξ^-K^+. This conclusion depends crucially on the $\underline{20}$ dominance for the effective Hamiltonian.

I also list the two-body decays of the charged charmed (metastable) particles since it may be useful for charm searches:

$$B^+(\tfrac{1}{2}{}^+, I=\tfrac{1}{2}, Y=-1, C=1)$$

$$\to \Sigma^+\pi^0, \Sigma^+\eta, p\overline{K}{}^0, \Sigma^0\pi^+, \Lambda\pi^+,$$

$$B^+(\tfrac{1}{2}{}^+, I=0, Y=0, C=1) \to \Sigma^+\overline{K}{}^0, \Xi^0\pi^+,$$

$$\Delta^{++}(\tfrac{3}{2}{}^+, I=1, Y=0, C=1) \to \Sigma^+\pi^+,$$ (4)

$$\Delta^+(\tfrac{3}{2}{}^+, I=1, Y=0, C=1)$$

$$\to \Sigma^+\pi^0, \Sigma^+\eta, p\overline{K}{}^0, \Sigma^0\pi^+, \Lambda\pi^+,$$

$$\Delta^+(\tfrac{3}{2}{}^+, I=\tfrac{1}{2}, Y=-1, C=1) \to \Sigma^+\overline{K}{}^0, \Xi^0\pi^+.$$

Note that the doubly charged metastable particles will exist at around 3.6 GeV ($C=1$) and around 4.7 GeV ($C=2$).

Finally I would like to point out that there is an event which supports the above consideration. Hoshino et al.[11] found a "vee" event in an emulsion which was exposed to the proton beam with momentum of 205 GeV/c at the Fermi National Accelerator Laboratory. Their results are as follows (see Ref. 2 for the details): The angles of emission of each charged particle relative to an assumed neutral line are 3.68×10^{-2} and 2.01×10^{-2} rad, respectively. Coplanarity is well

satisfied. They estimated the momenta of these charged particles (I refer to them as m and n, respectively, hereafter) as 14.6 ± 3 and 26.7^{+5}_{-4} GeV/c, respectively. I assume that this event is due to a decay of a neutral particle into two charged particles. Then we can estimate[11] the mass of the neutral parent particle, after identifying the daughter charged particles.

One may throw away the possibility that this "vee" event is due to K^0 or Λ decay, since the estimated parent masses are 1.16 ± 0.21 and 1.94 ± 0.13 (or 1.64 ± 0.15) GeV, if the daughter particles are $\pi\pi$ and $p\pi$ (or πp), respectively. (I take the ordering of the particles as mn.) Further I believe that the estimated masses, 1.1, 1.3, and 1.4 GeV in the cases of $\pi\pi$, πK, and $K\pi$, respectively, are too low for the charmed pseudoscalar mesons. Thus I assume that the "vee" event is due to the decay of a charmed baryon. The possible decay modes are, from the above analysis, ΣK, ΞK, and $\Sigma\pi$. The estimated masses are 2.4 (2.0), 2.5 (2.0), and 2.3 (1.9), respectively. (The numbers in the parentheses correspond to the cases $K\Sigma$, $K\Xi$, and $\pi\Sigma$, respectively. I do not consider these numbers further, since they seem too small for the charmed baryons.) The numbers 2.4, 2.5, and 2.3 GeV are consistent with those I have derived in Table I. This indicates that the "vee" event can be interpreted as the decay of a charmed baryon.

In conclusion, the negative results in the charmed-particle searches, especially in the channels $\pi^\pm K^\mp$ and pK^-, are not really in conflict with the charm scheme. Searches in the channels suggested above are crucial for the charm scheme.

---

[1]S. L. Glashow, J. Iliopoulous, and L. Maiani, Phys. Rev. D **2**, 1285 (1970); see also Y. Katayama, K. Matsumoto, S. Tanaka, and E. Yamada, Progr. Theor. Phys. **28**, 675 (1962); Z. Maki, Prog. Theor. Phys. **31**, 331, 333 (1964); Y. Hara, Phys. Rev. **134**, B701 (1964); B. J. Bjørken and S. L. Glashow, Phys. Lett. **11**, 255 (1964); D. Amati, H. Bacry, J. Nuyts, and J. Prentki, Phys. Lett. **11**, 190 (1964).

[2]K. Niu, E. Mikumo, and Y. Maeda, Progr. Theor. Phys. **46**, 1644 (1971); T. Matsubayashi et al., to be published.

[3]K. Hoshino et al., Department of Physics, Nagoya University, Report No. DPNU-3 (to be published); P. L. Jain and B. Girard, Phys. Rev. Lett. **34**, 1238 (1975).

[4]C. Baltay et al., Phys. Rev. Lett. **34**, 119 (1975);

A. M. Boyarski *et al.*, Phys. Rev. Lett. <u>35</u>, 195 (1975); E. J. Bleser *et al.*, Phys. Rev. Lett. <u>35</u>, 76 (1975).

[5]Glashow, Iliopoulous, and Maiani, Ref. 1.

[6]J. J. Aubert *et al.*, Phys. Rev. Lett. <u>33</u>, 1404 (1974); J.-E. Augustin *et al.*, Phys. Rev. Lett. <u>33</u>, 1406 (1974), and <u>34</u>, 1407 (1975); G. S. Abrams *et al.*, Phys. Rev. Lett. <u>33</u>, 1453 (1974).

[7]Y. Iwasaki, Phys. Rev. Lett. <u>34</u>, 1407 (1975).

[8]E. G. Cazzoli *et al.*, Phys. Rev. Lett. <u>34</u>, 1125

(1975).

[9]S. Okubo, V. S. Mathur, and S. Borchardt, Phys. Rev. Lett. <u>34</u>, 236 (1975).

[10]G. Altarelli, N. Cabibbo, and L. Maiani, Nucl. Phys. <u>B88</u>, 285 (1975); Iwasaki, Ref. 7; G. Altarelli, N. Cabibbo, and L. Maiani, Laboratorio di Fisica, Istituto Superiore di Sanità, Rome, Report No. ISS P 75/4 (to be published).

[11]Hoshino *et al.*, Ref. 3.

Structured KCl:Tl Emission Detected by Electric Field: A Dynamical Jahn-Teller Effect Interpretation

A. Ranfagni, G. P. Pazzi, P. Fabeni, and M. Bacci

Istituto di Ricerca sulle Onde Elettromagnetiche del Consiglio Nazionale delle Ricerche, Firenze, Italy

and

M. P. Fontana and G. Viliani

Istituto di Fisica dell'Università di Parma, Parma, Italy

(Received 3 June 1975)

The temperature dependence of the triplet structure detected by electric field on the 3000-Å emission of KCl:Tl has been studied. The splitting follows a $\sqrt{T}$ law, in agreement with a model based on the dynamical Jahn-Teller effect.

Stark-effect measurements on the emission of KBr:Tl phosphors were performed at liquid nitrogen temperature by Giorgianni, Grasso, and Perillo,[1,2] and showed a well-resolved triplet structure in both high- and low-energy emission; in spite of the novelty of this result and the lacking of any adequate interpretation, this subject was not investigated any further.

In this Letter we report the results of similar experiments performed at various temperatures on the 3000-Å emission of KCl:Tl. This phosphor is well suited for this kind of research as the intensity of its prominent 3000-Å emission is fairly constant through the range of temperature considered. We found that the triplet structure evidenced by the electric field is present at all temperatures between 10 and 300 K and that the splitting increases with temperature. These facts are here interpreted in terms of the dynamical Jahn-Teller effect.

Single crystals of KCl:Tl (thallium concentration ~30 ppm, sample size $10 \times 10 \times 1$ mm^3) were mounted in a cryostat between two electrodes (one of which was semitransparent), and a sinusoidal electric field (50 kV$_{\mathrm{rms}}$/cm, 500 Hz) was applied in the same direction as the exciting light. Emission was observed at right angle. The experimental setup was similar to the one described in Ref. 2.

Our results are displayed in Fig. 1. We note that the relative change of the emission, $\Delta I/I$, shows a nearly symmetric triplet structure at all temperatures; the splitting increases with temperature from ~0.1 eV at 10 K to ~0.2 eV at 300 K. With increasing temperature the structure becomes less prominent since the maximum-to-minimum ratio decreases considerably as a result of a larger negative variation of the zero moment of the emission band.

A similar electric-field–induced structure was observed in the absorption bands[2,3] and was related to Toyozawa and Inoue's model[4] which accounts for the triplet shape of the absorption bands observed with no external field. Here an explantion of the electric-field–induced structure of the *emission* bands is proposed and is based on the hypothesis that the transitions arise from the three branches of the triplet state as split by coupling to the trigonal vibrational modes, and that consequently each emission band is actually composed of three different sub-bands. In other words, we think that the Jahn-Teller effect—responsible for the structure of the no-field absorption bands—also engenders the structured emission as revealed by the electric field. The application to the phosphor of such field is expected