# ELECTROMAGNETIC INTERACTIONS AND SU(3) ${ }^{*}$ by <br> Haim Harari ${ }^{\dagger}$ <br> Stanford Linear Accelerator Center Stanford University, Stanford, California 

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## I. INTRODUCTION

In the last few years we have witnessed a significant increase in our experimantal understanding of the electromagnetic interactions of the strongly interacting particles. With the operation of CEA and DESY, electron accelerators entered the multi-BeV region for the first time, enabling us to study electron and photon initiated processes up to 6 BeV , while more (and better) measurements of the "intrinsic properties" of the particles (e.g., electromagnetic mass differences, magnetic moments, radiative decay widths) were carried out. The outlook for the next few years is even more promising with the first glance into the $6-20 \mathrm{BeV}$ region at SLAC. Among the interesting phenomenological aspects of the new experimental findings, the comparison of $\operatorname{SU}(3)$ predictions with the data plays a special role. On one hand we obtain better understanding of the $\mathrm{SU}(3)$ transformation properties of the hadronic electromagnetic current, while at the same time we gain some insight into the reaction mechanisms of high energy photoproduction processes, by using $\operatorname{SU}(3)$ relations as a new guide in deciding in which channel a particular process is simple and what particles (or Regge trajectories) are exchanged in this channel.

In this talk I will review the present experimental situation with respect to ths $\mathrm{SU}(3)$ predictions for electromagnetic mass differences, magnetic moments, electromagnetic decays and photoproduction reactions including pseudoscalar and vector meson productions.

## II. IS THE PHOTON A MEMBER OF AN OCTET?

Before we can discuss any $\operatorname{SU}(3)$ aspects of electromagnetic processes we have to ask ourselves what is the $\mathrm{SU}(3)$ character of the photon or, to be more
precise, what are the transformation properties of the electromagnetic current of the hadrons.

All the known hadrons seem to obey the Gell-Mann-Nishijima relation:

$$
\begin{equation*}
\mathrm{Q}=\mathrm{I}_{\mathrm{z}}+\frac{1}{2} \mathrm{Y} \tag{1}
\end{equation*}
$$

 them must belong to an octet. The electric charge is therefore in an octet, at least as long as Eq. (1) holds. It is conceivable that there exists an additional quantum number which we may call "charm" ${ }^{1}$ and which should be added to Eq. (1). All the presently known particles have charm $c=0$ and are "charmless", but some day we may find "charming" particles (quarks?) having $c= \pm 1$ (the same way that until the $K$ and $\Lambda$ were discovered all particles were non-strange). The charm quantum number could transform like an $\mathrm{SU}(3)$ representation other than the octet, and in that case the total electric charge $Q$ will have components in the octet as well as in some other representation. All the known particles, however, have $c=0$ and therefore have vanishing matrix elements for the nonoctet part of the electric charge. We therefore conclude that, independent of possible future modifications of the Gell-Mann-Nishijima relation (1), only octet parts of the charge $Q$ may have non-vanishing matrix elements between the existing particles.

Once we have decided that the charge belongs to an octet we can proceed to discuss the transformation properties of the current. The charge is related to the current by the relation

$$
\begin{equation*}
Q=\int j_{0}(\vec{x}, t) d^{3} \vec{x} \tag{2}
\end{equation*}
$$

Equation (2) implies that at least part of the electromagnetic current transforms like a component of an octet. We also learn that, if some "piece" of the current transforms like any other representation, its integral over space has to vanish, and will not contribute to the charge. Such a possibility cannot be apriori ruled out and we have to consider it carefully. The simplest possibility for a non-octet part would be to assume that part of the current belongs to an $\mathrm{SU}(3)$ singlet. How can we test such an idea? Normally we would simply derive as many predictions as we can, assuming that the current is a pure octet, and study their agreement with experiment. Strong deviations from these predictions might indicate that the octet assumption is misleading and that additional terms exist. It turns out, however, that there is a technical difficulty in pursuing this simple procedure in our case. The octet part of the current is a U-spin singlet. If the current includes an $\mathrm{SU}(3)-$ singlet term, it will also be a U-spin singlet. This means that those $S U(3)$ predictions which can be derived on the basis of U-spin conservation alone cannot distinguish between the octet part and the (possible) singlet part of the electromagnetic current? As we will see throughout this talk, most of the predictions of $\mathrm{SU}(3)$ for electromagnetic processes actually follow from U-spin conservation alone and cannot be utilized to probe the exact transformation properties of the current. This makes the identification of the representation of the current a very difficult problem but on the other hand, it is, of course, comforting to know that most of our predictions do not depend on the possible existence of an $\mathrm{SU}(3)$ singlet term in the current.

Among the few predictions that do depend on the assignment of the current, we would like to emphasize one which actually enables us to "measure" the octet and singlet parts of the current. We consider the decay of the neutral vector mesons
$\rho^{0}, \omega$ and $\phi$ to lepton pairs, and assume that the decay proceeds via a virtual photon (Fig. 1). This assumption


Fig. 1
is probably safe, since the diagram of Fig. 1 is the only one that contributes to lowest order in $\alpha$. The ratio between the decay widths for $\rho^{\circ}, \omega$ and $\phi$ actually "measures" the ratio between the "direct" coupling constants $g_{\rho \gamma}^{2}, g_{\omega \gamma}^{2}$ and $g_{\phi \gamma}^{2}$. Since we believe that $\rho^{0}$ is in the octet while $\omega$ and $\phi$ correspond to well-defined octet-singlet combinations:

$$
\begin{align*}
& \omega=\omega_{8} \sin \theta+\omega_{1} \cos \theta  \tag{3}\\
& \phi=\omega_{8} \cos \theta-\omega_{1} \sin \theta
\end{align*}
$$

we predict that, if the electromagnetic current is purely in the octet represenataion:

$$
\begin{equation*}
\mathrm{g}_{\rho \gamma}^{2}: \mathrm{g}_{\omega \gamma}^{2}: \mathrm{g}_{\phi \gamma}^{2}=3: \sin ^{2} \theta: \cos ^{2} \theta \tag{4}
\end{equation*}
$$

Since $\sin ^{2} \theta$ is believed to be around $1 / 3$, we predict: ${ }^{2}$

$$
\begin{equation*}
\Gamma\left(\rho^{\circ} \rightarrow l^{+} \ell^{-}\right): \Gamma\left(\omega \rightarrow l^{+} \ell^{-}\right): \Gamma\left(\phi \rightarrow l^{+} l^{-}\right)=9: 1: 2 \mathrm{f} \tag{5}
\end{equation*}
$$

where $f$ is a kinematic correction due to the mass difference between $\phi$ and $\rho$ or $\omega\left(\mathrm{m}_{\rho} \sim \mathrm{m}_{\omega}\right)$. A branching ratio $\Gamma\left(\rho^{0} \rightarrow \mu^{+} \mu^{-}\right) / \Gamma\left(\rho^{0} \rightarrow \pi \pi\right)$ has recently been mcasured by various groups ${ }^{3}$ with an average result:

$$
\begin{equation*}
\frac{\Gamma\left(\rho \rightarrow \mu^{+} \mu^{-}\right)}{\Gamma(\rho \rightarrow \text { all })}=(6 \pm 1) 10^{-5} \tag{6}
\end{equation*}
$$

Using the experimental total widths ${ }^{4}$ of $\omega$ and $\phi$, Eq. (5) predicts:

$$
\begin{align*}
& \frac{\Gamma\left(\omega \rightarrow \mu^{+} \mu^{-}\right)}{\Gamma(\omega \rightarrow \text { all })} \sim 7 \times 10^{-5}  \tag{7}\\
& \frac{\Gamma\left(\phi \rightarrow \mu^{+} \mu^{-}\right)}{\Gamma(\phi \rightarrow \text { all })} \sim 5 f \times 10^{-4} \tag{8}
\end{align*}
$$

No reliable values are available for $\omega, \phi \rightarrow \ell^{+} \ell^{-}$while the present upper limits are consistent with the predictions. The ambiguity introduced by the kinematic factor f is probably of the order of $\left(\mathrm{m}_{\phi} / \mathrm{m}_{\rho}\right)^{2} \sim 1.8$, so that the prediction (8) should be correct only within a factor of two. Intuitive arguments based on the algebra of currents actually suggest that $\mathrm{f}=\left(\mathrm{m}_{\rho} / \mathrm{m}_{\phi}\right)^{2}$ leading to

$$
\begin{equation*}
\frac{\Gamma\left(\phi \longrightarrow l^{+} \ell^{-}\right)}{\Gamma(\phi \longrightarrow \text { all })} \sim 3 \times 10^{-4} \tag{9}
\end{equation*}
$$

A strong deviation of experiment from the predictions (7) - (9) would indicate that the electromagnetic current actually has a term outside the octet representation. We will encounter a few additional SU(3) predictions which depend on the octet properties of the photon and we will mention them as we go along.

## III. ELECTROMAGNETIC MASS DIFFERENCES

Together with the Gell-Mann-Okubo mass formula, the Coleman-Glashow relation for the electromagnetic mass differences of the baryon octet is probably the most spectacular triumph of $\operatorname{SU}(3)$. Assuming that the photon is a U -spin singlet one finds:

$$
\begin{equation*}
\left(m_{n}-m_{p}\right)+\left(m_{\Xi^{-}}-m_{\Xi^{0}}\right)=\left(m_{\Sigma^{-}}-m_{\Sigma^{+}}\right) . \tag{10}
\end{equation*}
$$

Experimentally the values for the l.h.s. and r.h.s. are (7.8 $\pm 0.2$ ) and $(7.97 \pm 0.11) \mathrm{MeV}$, respectively. ${ }^{4}$ If you study the time variation of these numbers since 1962 , you will actually find that they are converging to the right values:

Other relations between electromagnetic mass differences include:

$$
\begin{array}{r}
\mathrm{m}_{\Xi^{*-}}^{-\mathrm{m}} \Xi^{* O}=\mathrm{m}_{\mathrm{Y}_{1}^{*-}} \mathrm{Y}_{1}^{* \mathrm{O}^{-}}=\mathrm{m}_{\mathrm{N}^{*-}} \mathrm{m}^{* O} \\
\mathrm{~m}_{\mathrm{Y}_{1}^{* 0}}-\mathrm{m}_{\mathrm{Y}_{1}^{*+}}=\mathrm{m}_{\mathrm{N}^{* 0}}-\mathrm{m}_{\mathrm{N}^{*+}} \tag{12}
\end{array}
$$

The data for these masses are not sufficient, and depend on too many phenomenological assumptions to be taken seriously. As long as the "mass" of a given resonance depends on the kind of experiment in which it was produced, it is dangerous to rely on measurements of mass differences between two charge states of the same resonance.

## IV. MAGNETIC MOMENTS

The isotopic spin nature of the electromagnetic current leads to one relation among the magnetic moments of the baryon-octet:

$$
\begin{equation*}
\mu\left(\Sigma^{+}\right)+\mu\left(\Sigma^{-}\right)=2 \mu\left(\Sigma^{\mathrm{O}}\right) \tag{13}
\end{equation*}
$$

If the current is a U-spin singlet (not necessarily in the octet) we obtain three additional predictions:

$$
\begin{align*}
& \mu(\mathrm{p})=\mu\left(\Sigma^{+}\right)  \tag{14}\\
& \mu(\mathrm{n})=\mu\left(\text { 没 }^{\mathrm{O}}\right)  \tag{15}\\
& \mu\left(\Sigma^{-}\right)=\mu\left(\Xi^{-}\right)  \tag{16}\\
&-6-
\end{align*}
$$

If, furthermore, the current is an arbitrary mixture of octet and singlet, we find:

$$
\begin{equation*}
3 \mu(\Lambda)+\mu\left(\Sigma^{0}\right)=2 \mu(\mathrm{n}) \tag{17}
\end{equation*}
$$

Finally, if the current is "purely" in the octet:

$$
\begin{equation*}
\mu(\Lambda)=\frac{1}{2} \mu(\mathrm{n}) \tag{18}
\end{equation*}
$$

For an octet current we have six predictions [Eqs. (13)-(18)] which enable us to express all the moments in the octets in terms of two of them say, $\mu(\mathrm{p})$ and $\mu(\mathrm{n})$. Using $\mu(\mathrm{p})=2.8$ and $\mu(\mathrm{n})=-1.9$, we predict:

$$
\begin{align*}
& \mu(\Lambda)=-0.95, \quad \mu\left(\Sigma^{+}\right)=2.8, \quad \mu\left(\Sigma^{0}\right)=0.95, \\
& \mu\left(\Sigma^{-}\right)=-0.9, \quad \mu\left(\Xi^{0}\right)=-1.9, \quad \mu\left(\Xi^{-}\right)=-0.9 \tag{19}
\end{align*}
$$

Expcrimental information is available ${ }^{4,5}$ for $\mu(\Lambda)$ and $\mu\left(\Sigma^{+}\right)$:

$$
\begin{equation*}
\mu(\Lambda)=-0.73 \pm 0.16 \quad \mu\left(\Sigma^{+}\right)=3.2 \pm 0.9 \tag{20}
\end{equation*}
$$

Since the predictions (13)-(18) prcsumably hold only in the limit of equal masses we should accept them only within $20 \%-30 \%$. In particular, we have no solid reason to interpret the predictions as relations between the magnetic moments rather than between the g-factors, and this ambiguity introduces an uncertainty of the order $m_{\Lambda} / m_{N}$ for the predicted value of $\mu(\Lambda)$, etc. Within the limitation of this ambiguity, the experimental values of Eq. (20) can be considered a success for $\operatorname{SU}(3)$. Moreover, the approximate agreement between Eq. (18) and the experimental $\mu(\Lambda)$ is the only indication that we have, at present, that no substantial contributions of representations other than the octet exist.

## V. THE DECAYS $\pi, \boldsymbol{\eta} \longrightarrow 2 \gamma$

A particularly simple and elegant prediction for the ratio $\left(\pi^{\circ} \rightarrow \gamma \gamma\right) /(\eta \longrightarrow \gamma \gamma)$ can be derived from the assumption that the photon is a $U$-spin scalar. In order to derive it we construct the particular combination of $\pi^{\circ}$ and $\eta$ which transforms like a vector under $U$-spin, and notice that the transition between this combination and the two-photon state is forbidden by $U$-spin conservation. This immediately leads to:

$$
\begin{equation*}
3 \bar{\Gamma}(\eta \rightarrow \gamma \gamma)=\bar{\Gamma}\left(\pi^{0} \rightarrow \gamma \gamma\right) \tag{21}
\end{equation*}
$$

where $\bar{\Gamma}$ is the width, corrected by the kinematic phase space factor. Since the two photons have to be in a p-wave relative to each other, the phase space correction factor is $\left(m_{\eta} / m_{\pi}\right)^{3}=64$. The predicted ratio for the actual width is therefore:

$$
\begin{equation*}
\Gamma(\eta \longrightarrow \gamma \gamma) \sim 21 \Gamma\left(\pi^{0} \longrightarrow \gamma \gamma\right) \tag{22}
\end{equation*}
$$

But, of course, it is very hard to take such a prediction seriously in view of the huge $\pi-\eta$ mass difference. Experimentally $\Gamma\left(\pi^{0} \rightarrow \gamma \gamma\right) \sim 8-10 \mathrm{eV}$, while a recent measurement ${ }^{6}$ of $\Gamma(\eta \longrightarrow \gamma \gamma)$ in the Primakoff effect yielded: $\Gamma(\eta \rightarrow \gamma \gamma)=(1.21 \pm 0.26) \mathrm{keV}$, i. e., approximately six times larger than predicted by exact $\operatorname{SU}(3)$ [Eq. (22)]. The source of this discrepancy is not clear and it would be interesting to try to find a dynamical description of these processes which would enable us to take into account the effect of the $\eta-\pi$ mass ratio on the matrix element itself.

## VI. RADIATIVE DECAYS: $\mathrm{A} \longrightarrow \mathrm{B}+\gamma$

Among the interesting $\operatorname{SU}(3)$ predictions for processes of the type $\mathrm{A} \rightarrow \mathrm{B}+\gamma$ where $A, B$ are hadrons we would like to mention three:

U -spin conservation leads to peculiar predictions for the decays $\mathrm{Y}_{1}^{*}(1385) \mapsto \Sigma+\gamma$ :

$$
\begin{gather*}
\bar{\Gamma}\left(\mathrm{Y}_{1}^{*+}(1385) \longrightarrow \Sigma^{+} \gamma\right)=\bar{\Gamma}\left(\mathrm{N}^{*+}(1238) \rightarrow \mathrm{p} \gamma\right)  \tag{23}\\
\Gamma\left(\mathrm{Y}_{1}^{*-} \rightarrow \Sigma^{-} \gamma\right)=0 \tag{24}
\end{gather*}
$$

The width for $\mathrm{N}^{*+} \rightarrow \mathrm{p} \gamma$ is known from the photoexcitation of the $\mathrm{N}^{*}$ and is 0.65 McV . The decay $\mathrm{Y}_{1}^{*+} \Sigma^{+} \gamma$ is therefore predicted to be of the same (appreciable) strength while $\mathrm{Y}_{1}^{*-} \rightarrow \Sigma^{-} \gamma$ is forbidden by exact $\mathrm{SU}(3)$ and should be significantly smaller. No data are available for these decays, but there are good chances that in the next few years we will be able to test these predictions.

Another set of radiative decays that we consider here involves transitions that are forbidden if the photon is in the octet but could be otherwise allowed. The smallness of such transitions, if verified experimentally, would add new evidence for the octet assignment of the current. The forbidden decays are:

$$
\begin{align*}
& \mathrm{Y}_{0}^{*}(1520) \longrightarrow \mathrm{Y}_{1}^{*}(1385)+\gamma  \tag{25}\\
& \mathrm{Y}_{0}^{*}(1520) \longrightarrow \mathrm{Y}_{0}^{*}(1405)+\gamma \tag{26}
\end{align*}
$$

where we have assumed that the 1520 and $1405 \mathrm{Y}^{*}$ 's are in $\operatorname{SU}(3)$ singlets.
Our last group of radiative decays includes $\rho \rightarrow \pi \gamma, \omega \rightarrow \pi \gamma$ and $\phi \longrightarrow \pi \gamma$. If the photon is in the octet and $\phi$ and $\omega$ are given by Eq. (3) with $\sin ^{2} \theta=1 / 3$, we predict:

$$
3 \mathrm{~g}_{\rho \pi \gamma}=\sqrt{2} \mathrm{~g}_{\phi \pi \gamma}+\mathrm{g}_{\omega \pi \gamma}
$$

where $\mathrm{g}_{\mathrm{V} \pi \gamma}^{2} \propto \Gamma(\mathrm{~V} \rightarrow \pi \gamma)$.
In order to reach more definitive predictions we must invoke more speculative models which are either stronger than, or different from, $\mathrm{SU}(3)$. At least four
independent models of this nature predict that the $\phi \pi \gamma$ coupling is very small. These are:

1. In quark models the $\phi \pi \gamma$ vertex is forbidden if we assume that $\phi$ is a $\bar{\lambda} \bar{\lambda}$ state and that the electromagnetic transition occurs by the emission of a photon by one of the quarks.
2. $\operatorname{SU}(6)_{\mathrm{W}}$ forbids the decay $\phi \rightarrow \pi^{0}+\gamma$ if the $\phi$ is identified as a singlet of the spin-isospin subgroup $\operatorname{SU}(4)_{\mathrm{I}}$. This is the assignment implied by the mass formula.
3. Since the photon emitted in the decay $\phi \rightarrow \pi^{\circ}+\gamma$ is pure isovector we may assume that it is dominated by the $\rho$-meson. The partial width $\Gamma\left(\phi \rightarrow \pi^{\circ}+\gamma\right)$ will then be suppressed by the small $\phi \rho \pi$ coupling constant.
4. If we assign the $\phi$ state moving at infinite momentum to a $(0,0)$ representation of the chiral $\mathrm{SU}(2) \times \mathrm{SU}(2)$ algebra of integrated currents, we can use PCAC to show that $\Gamma\left(\phi \rightarrow,^{\circ}+\gamma\right)$ is small compared to, say, $F\left(\omega \rightarrow 7^{\circ}+\gamma\right)$. This is based on the fact that the axial charge is a generator of the algebra and cannot connect a state in the $(0,0)$ representation to an isovector photon. If the matrix element for a pionic decay is proportional to that of the axial charge, we obtain that in this approximation $\phi \longrightarrow \pi+\gamma$ is forbidden.

If we accept any of these arguments (which are consistent with the fact that $\phi \rightarrow \pi \gamma$ has never been seen), and assume

$$
\Gamma(\phi \rightarrow \pi \gamma)=0
$$

we predict:

$$
\begin{equation*}
\Gamma(\omega \rightarrow \pi \gamma)=9 \Gamma(\rho \rightarrow \pi \gamma) \tag{27}
\end{equation*}
$$

Experimentally ${ }^{4} \Gamma(\rho \rightarrow \pi \gamma) / \Gamma(\omega \rightarrow \pi \gamma) \leq 1 / 2$.

## VII. PHOTOPRODUCTION OF PSEUDOSCALAR MESONS

SU(3) predictions for reactions are usually expressed as relations between the various relevant amplitudes. Since the relative phases of these amplitudes are not known we have to translate the equalities among amplitudes into inequalities among square roots of cross sections.

In order to compare our results with experiment we will follow the prescription of first dividing the experimental cross sections by appropriate phase-space factors, and then applying the predictions to the "corrected" cross sections which we shall denote by $\bar{\sigma}$. In addition, we define

$$
\mathrm{R}(\mathrm{ab} \ldots)=[\bar{\sigma}(\gamma+\mathrm{p}-\mathrm{a}+\mathrm{b}+\ldots)]^{1 / 2} .
$$

$R(a b . .$.$) is proportional to the absolute value of the amplitude for photoproduction$ of the system $\mathrm{a}+\mathrm{b}+\ldots$ and most of our predictions will be given as inequalities among the $R$ values of different reactions. Since most of our results are derived by assuming only that the photon is a U -spin singlet, they cannot test the octet assignment of the electromagnetic current. In all $\gamma+\mathrm{p}$ processes the initial state has $U=1 / 2$. The number of independent amplitudes is, therefore, determined by the number of possible ways of constructing a $U=1 / 2$ state from the reaction products.

Two inequalities can be obtained ${ }^{7}$ for photoproduction of a single pseudoscalar meson and a baryon:

$$
\begin{align*}
& \mathrm{R}\left(\pi^{+} \mathrm{n}\right) \leq \frac{1}{2} \sqrt{6} \mathrm{R}\left(\mathrm{~K}^{+} \Lambda\right)+\frac{1}{2} \sqrt{2} \mathrm{R}\left(\mathrm{~K}^{+} \Sigma^{0}\right),  \tag{28}\\
& \mathrm{R}\left(\pi^{0} \mathrm{p}\right) \leq \sqrt{2} \mathrm{R}\left(\mathrm{~K}^{\mathrm{o}} \Sigma^{+}\right)+\sqrt{3} \mathrm{R}(\eta \mathrm{p}) \tag{29}
\end{align*}
$$

The prediction (28) agrees with the data ${ }^{8}$ for $3.4<\mathrm{E}_{\gamma}<4 \mathrm{BeV}$ and center-ofmass angles between $25^{\circ}$ and $45^{\circ}$. The total cross sections are not known too well
at high energies but there are some indications ${ }^{9}$ that they may not obey (28). The situation with respect to the relation (29) is not clear.

Some additional relations which can be obtained for the production of pseudoscalar mesons are ${ }^{10}$

$$
\begin{align*}
2 \bar{\sigma}\left(\gamma+\mathrm{p} \longrightarrow \pi^{+}+\mathrm{K}^{+}+\Sigma^{-}\right) & \geq \bar{\sigma}\left(\gamma+\mathrm{p} \longrightarrow \mathrm{~K}^{+}+\mathrm{K}^{+}+\Xi^{-}\right)  \tag{30}\\
\mathrm{R}\left(\pi^{+} \pi^{-} \mathrm{p}\right) & \leq \mathrm{R}\left(\mathrm{~K}^{+} \mathrm{K}^{-} \mathrm{p}\right)+\mathrm{R}\left(\mathrm{~K}^{+} \pi^{-}{\Sigma^{+}}^{+}\right)  \tag{31}\\
\bar{\sigma}\left(\pi^{+} \mathrm{N}^{*} \mathrm{O}\right) & =2 \bar{\sigma}\left(\mathrm{~K}^{+} \mathrm{Y}_{1}^{* \mathrm{O}}\right) \tag{32}
\end{align*}
$$

The inequality (30) applies only to the total (integrated over all angles) cross section for producing $\pi^{+} \mathrm{K}^{+} \Sigma^{-}$. At any given angle we obtain a sum rule of the form
$\mathrm{A}\left(\gamma+\mathrm{p} \rightarrow \pi^{+}+\mathrm{K}^{+}+\Sigma^{-}\right)+\mathrm{A}\left(\gamma+\mathrm{p}-\mathrm{K}^{+}+\pi^{+}+\Sigma^{-}\right)=\mathrm{A}\left(\gamma+\mathrm{p} \rightarrow \mathrm{K}^{+}+\mathrm{K}^{+}+\Xi^{-}\right)$,
where A is the (complex) amplitude for producing the first meson in a given direction and the second meson in some other definite angle. There are only a few known events of the processes appearing in (30) and we can make no significant comparison with the data.

The relation (31) was recently compared with the bubble-chamber data. ${ }^{11}$ The left-hand and right-hand sides are, respectively, 12 and 9 (in arbitrary units) with errors of the order of 10-20 percent. This includes, however, only nonresonant events, eliminating a huge number of $\pi^{+} \pi^{-}$events which come from $\rho^{\circ}$ decays. The prediction (31) should hold, however, even if we include the resonant events, provided that we use an appropriate phase-space correction. Using all events (both resonant and nonresonant) we find that the left-hand side of (31) is larger than the right-hand side by a factor of 2 .

Equation (32) seems to agree with the results of CEA and DESY who indicate very small cross sections for both reactions above 2 BeV .

Many additional $\operatorname{SU}(3)$ predictions for photoproduction processes can be easily obtained, but the data do not enable us to draw any conclusions. ${ }^{10}$

## VIII. PHOTOPRODUCTION OF NEUTRAL VECTOR MESONS

The photoproduction of neutral vector mesons is a process of great interest from many points of view. The production mechanism at high energies seems to be very similar to that of ordinary elastic processes such as $\pi p$ or Kp elastic scattering. The three processes $\gamma p \rightarrow \rho^{\circ} \mathrm{p}, \omega \mathrm{p}$, and $\phi \mathrm{p}$ supply us with an excellent testing ground for various quasi-elastic mechanisms such as Pomeranchon exchange, diffraction scattering, and theoretical ideas such as vector meson dominance. We can also use these processes (on nuclei) as indirect measurements of the vector-meson-nucleon total and elastic cross sections. Here we will be primarily concerned with the predictions of $\operatorname{SU}(3)$ for the relative production rates for $\rho^{\circ}, \omega$ and $\phi$.

Without assuming any specific mechanism for the reactions, $\mathrm{SU}(3)$ predicts:

$$
\begin{equation*}
\mathrm{R}\left(\rho^{\circ} \mathrm{p}\right) \leq \sqrt{2} \mathrm{R}\left(\mathrm{~K}^{* \mathrm{O}} \Sigma^{+}\right)+\mathrm{R}(\omega \mathrm{p})+\sqrt{2} \mathrm{R}(\phi \mathrm{p}) \tag{34}
\end{equation*}
$$

The present data indicates that at energies up to 6 BeV the left-hand side of Eq. (34) is larger than the right-hand side by approximatcly a factor of 2 . This already implies that $\operatorname{SU}(3)$ is badly broken here, and that if we now assume that a specific dynamical mechanism dominates the processes of Eq. (34), we will have to introduce somewhere explicit $\operatorname{SU}(3)$-breaking, before we can understand the data.

The diffraction mechanism (or Pomeranchon exchange) implies that at high energies $\sigma\left(\mathrm{K}^{*} \Sigma^{+} \Sigma^{+}\right.$, will decrease while the $\rho^{\circ}, \omega$, and $\phi$ production cross sections
will remain constant. This implies that as $\mathrm{E} \longrightarrow \infty$ :

$$
\begin{equation*}
R\left(\rho^{0} p\right) \leq R(\omega p)+\sqrt{2} R(\phi p) \tag{35}
\end{equation*}
$$

If we furthermore specify that at high energies these processes are dominated by $\mathrm{SU}(3)$-singlet exchange we predict:

$$
\begin{equation*}
\bar{\sigma}\left(\rho^{\circ} \mathrm{p}\right): \bar{\sigma}(\omega \mathrm{p}): \bar{\sigma}(\phi \mathrm{p})=9: 1: 2 \tag{36}
\end{equation*}
$$

The ratio 9:1 between $\rho^{0}$ and $\omega$ production is, at present, consistent with experiment. ${ }^{12}$ The $\phi$ production cross section is, however, smaller ${ }^{13}$ by a factor of $10-20$ than predicted by Eq. $:(36)$. This hints that the $\operatorname{SU}(3)$ breaking effect that was indicated by the failure of our prediction (34), exhibits itself mostly in the $\rho: \phi$ or $\omega: \phi$ production ratio, and is responsible for a significant depression (by a factor of $10-20$ ) of $\sigma(\gamma p \rightarrow o p)$. What are the possible reasons for such a huge symmetry breaking effect?

A few sources for this "trouble" can be immediately noticed:

1. The present data are in the region $1-6 \mathrm{BeV}$, mostly at $1-3 \mathrm{BeV}$. In this region the $Q$-value for $\phi$-production is substantially smaller than that for $\rho$ or $\omega$ production and phase space factors, as well as the variable chosen as the basis for the comparison may have a nontrivial effect. In addition, the minimum momentum transfer needed for producing $\phi$ is larger than that for $\rho$ or $\omega$, a fact which might be essential for differential cross sections which are strongly peaked forward. However, all these effects (a) are not sufficiently large to cause such a huge discrepancy, and (b) should rapidly disappear for higher energies.
2. The coupling of the incoming photon to $\rho, \omega$ and $\phi$ may depend on the vector meson mass. ${ }^{14}$ Corrections of the order $\left(\mathrm{m}_{\phi} / \mathrm{m}_{\rho}\right)^{2}$ can contribute a factor 2 discrepancy to Eq. (3:6).
3. The assumption of $S U(3)$ singlet exchange may be wrong. The failure of Eqs. (34), (35) indicates, however, that this is an unlikely source of trouble since the contradiction with experiment exists independent of this assumption.
4. The most likely "explanation" is the statement that, for some reason, the elastic (or total) cross section for $\phi \mathrm{N}$ scattering is significantly smaller than that for $\rho \mathrm{N}$. This would be a similar (but much larger) effect to the one observed in $\pi p$ and Kp elastic scattering where it is conceivable that the two cross sections approach two different constant values at high energies. In $\mathrm{SU}(3)$ language this can be said by stating that the coupling of the Pomeranchon to the vector or pseudoscalar mesons is not $\operatorname{SU}(3)$ invariant. Notice that this statement is different from the possibility of an important $\mathrm{SU}(3)$-invariant contribution from octet exchange!

A simple model which explains this smallness of the $\phi \mathrm{N}$ cross section has been proposed by various authors ${ }^{15}$ who used the quark model or Regge theory (plus universality assumptions) to relate the cross sections for $\phi \mathrm{N}$ and $\rho \mathrm{N}$ scattering to $\pi \mathrm{N}$ and KN scattering. They found that the mechanism which is responsible for reducing $\sigma_{t}(\mathrm{KN})$ compared to $\sigma_{\mathrm{t}}(\pi \mathrm{N})$ can lead to a $\phi \mathrm{N}$ elastic cross section smaller by a factor of 5-7 from $\sigma_{e 1}(\rho \mathrm{~N})$. This, together with the possible term $\left(\mathrm{m}_{\phi} / \mathrm{m}_{\rho}\right)^{2}$ mentioned above, could lead to the observed discrepancy for $\phi$-photoproduction.

Indirect measurements of $\sigma_{\mathrm{t}}(\phi \mathrm{N})$ as well as better determinations of $\Gamma\left(\phi \rightarrow \ell^{+} \ell^{-}\right)$and $\sigma(\gamma \mathrm{p} \rightarrow \phi \mathrm{p})$ will enable us to have a better understanding of this puzzle, and to decide whether any of the above explanations are really responsible for this effect.

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