second rank Lie group which is compatible with the existence of these processes.

On the other hand, if the $\Delta Q = -\Delta S$ decays exist and Eq. (3a) is not satisfied, we would be led either to consider higher rank Lie groups, to abandon (iii), or to abandon the entire possibility of higher symmetries constructed on the basis of simple Lie groups. Simple Lie groups of rank higher than two involve additional quantum numbers for which there is no experimental evidence at present. An example of a Lie group of higher rank which contains the isotopic spin group and both $I = \frac{1}{2}$ and $I = \frac{3}{2}$ partially conserved currents is B_3 (R_7).[2] Since G_2 is a subgroup of B_3, it follows that the strong interaction predictions of G_2 also hold for B_3. Clearly, any higher rank group of which G_2 is a subgroup can lead to both $I=1$ and $I = \frac{3}{2}$ currents. However, it is not known to us whether this sufficient condition is also necessary.

The authors would like to thank R. Marr for a valuable discussion. One of us (A.S.) would like to thank D. Amati, S. M. Berman, B. D'Espagnat, S. MacDowell, T. D. Lee, R. Marshak, S. Okubo, J. R. Oppenheimer, and J. Prentki for several conversations on this subject during 1960 and 1961.

*Work supported in part by the U. S. Army Research Office, Durham, North Carolina.

[1]R. P. Ely et al., Phys. Rev. Letters 8, 132 (1962).

[2]R. E. Behrends and A. Sirlin, Phys. Rev. 121, 324 (1961).

[3]R. E. Behrends and A. Sirlin, Phys. Rev. Letters 5, 476 (1960).

[4]A. Pais, Nuovo cimento 18, 1003 (1960).

[5]It is only strictly necessary that such a current exist in the space-time vector (or axial vector) part of the current, whichever gives rise to the $(K^0)_{e3}$ decays—we shall denote it for convenience as the vector part.

[6]S. Okubo, R. E. Marshak, E. C. G. Sudarshan, W. B. Teutsch, and S. Weinberg, Phys. Rev. 112, 665 (1958).

[7]L. Okun', Ann. Rev. Nuclear Sci. 9, 61 (1959).

[8]T. D. Lee and C. N. Yang, Phys. Rev. 119, 1410 (1960).

[9]B. D'Espagnat, Nuovo cimento 18, 287 (1960).

[10]R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958).

[11]S. Glashow, Phys. Rev. Letters 6, 196 (1961).

[12]M. Gell-Mann, California Institute of Technology Synchrotron Laboratory Report CTSL-20, 1961 (unpublished). This symmetry is based on SU_3.

[13]R. E. Behrends, J. Dreitlein, C. Fronsdal, and B. W. Lee, Revs. Modern Phys. (to be published).

SIGN OF THE K_1-K_2 MASS DIFFERENCE

R. H. Good and E. Pauli
Laboratoire de Physique Corpusculaire à Haute Energie, Centre D'Etudes Nucléaires de Saclay, Saclay, France
(Received February 1, 1962)

Now that the magnitude of the K_1-K_2 mass difference has been measured,[1] attention is naturally directed towards the question of its sign. Kobzarev and Okun' have suggested[2] a method for experimentally determining this sign which makes use of the same transmission-regeneration phenomenon[3,4] used in measuring the magnitude. If K_2 mesons are passed successively through two plates of different materials, appropriately spaced (Fig. 1), then the transmission-regenerated K_1 meson intensity may be shown to be, roughly, proportional to $1 + \Delta\varphi$, where the sign depends on the sign of the mass difference and where

$$\tan\varphi_a = \left[\frac{\mathrm{Im}(f_+^{\,0} - f_-^{\,0})}{\mathrm{Re}(f_+^{\,0} - f_-^{\,0})}\right]_{\text{plate } a},$$

$$\Delta\varphi = \varphi_b - \varphi_a,$$

$f_+^{\,0}$ and $f_-^{\,0}$ being the K^0- and $\bar{K}^0$-nuclear forward-scattering amplitude.

The sign of $\Delta\varphi$ plays a role here equivalent to that of the sign of the mass difference, and so it is essential that $\Delta\varphi$'s sign, at any rate, be well

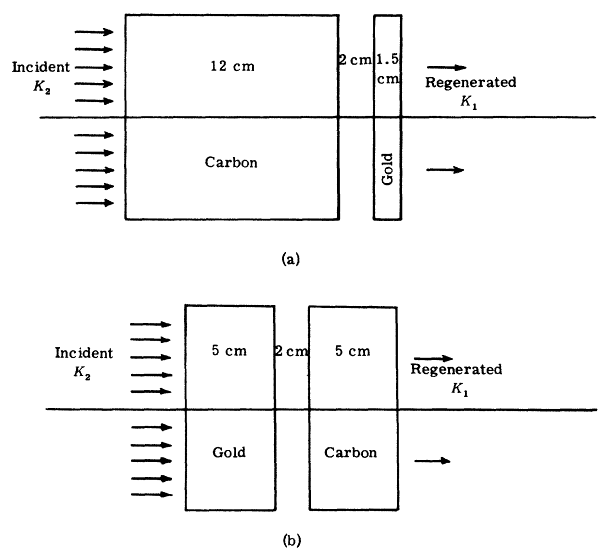

FIG. 1. Experimental arrangements for a Kobzarev-Okun' experiment at 565 Mev/c. Transmission-regenerated K_1 yield is about one per 1000-2000 K_2 incident. The thicknesses shown here are optimum for small $\Delta\varphi$ (not necessarily 0.17). (a) Carbon first; (b) gold first.

determined, i.e., that it not be too sensitive to the nuclear parameters involved in calculating it. In this note we present the results of a program of optical-model[5] calculations which indicate that $\Delta\varphi$ is probably negative and is probably about -0.17 when the first plate is carbon and the second is gold.[6] This conclusion is relatively independent of the nuclear model employed and depends only on the condition that $|V_-| < |W_-|$, where $V_- + iW_-$ is the K^--nuclear potential. If this is true, the experiment is feasible at the present time.

We use the Woods-Saxon potential,[7]

$$(V+iW)/\{1+\exp[(r-R)/a]\},$$

(r is distance from the center of the nucleus), to calculate the values of $f_{21}{}^0 = (f_+{}^0 - f_-{}^0)/2$ and of φ and its derivatives at 565 Mev/c. We assume K^+ and K^0 (and $\bar{K}^0, K^-$) form an isotopic doublet and thus show approximately the same nuclear potential. Zorn and Zorn[8] give $V_+ = 18.6$ Mev ± 20% for the K^+; when we correct this to Elton's nuclear parameters,[9] keeping the volume integral of the potential constant,[10] we obtain $V_+ = 22.5$ Mev. V_- is set equal to -22.5 Mev for these computations (see below). W_+ and W_- are obtained from the corresponding average K^+-nucleon and K^--nucleon total cross sections, which are taken as 15 mb[11] and 34 mb.[12] (Thus $W_+ = -18.7$ Mev, $W_- = -42.5$ Mev.) The values of R and a we use come from electron scattering experiments. Justification for this is as follows. It appears that all high-energy meson-nuclear scattering data may be fitted using the electron-scattering nuclear parameters plus a range of about 0 to 1 fermi.[9] This range is presumably due to the finite range of the meson-nucleon interaction. As this range is unknown we have not included it in our calculations; however, using $(\partial\Delta\varphi/\partial R)_A = 0.027$ (see below), we can conclude that a range of 1 fermi will change $\Delta\varphi$ by only about +0.027. Thus the electron data are adequate for an approximate calculation of $\Delta\varphi$.

The results are displayed in Table I. Some explanation of the significance of these quantities is necessary. $V_+(\partial\varphi/\partial V_+)$ is obtained by varying V_+ while keeping the other parameters fixed. The quoted error of ± 20% in V_+ thus corresponds to an error in $\Delta\varphi$ of ±0.066. The derivatives $(\partial\varphi/\partial a)_{\rho_0}$ and $(\partial\varphi/\partial R)_{\rho_0}$ are taken under the condition that the central density ρ_0 remain fixed; thus they correspond to changing from one nucleus to another, having the same central density but a different number of nucleons. Their small size explains why $\Delta\varphi$ is so small. The quantities $(\partial\varphi/\partial a)_A$ and $(\partial\varphi/\partial R)_A$ were obtained by varying the form of

Table I. Summary of results.

	Carbon	Gold	Difference (gold - carbon)
R(fermis)	2.30	6.38	
a	0.42	0.53	
$f_{21}{}^0$	$-2.78-1.36i$	$-15.93-4.59i$	
φ	0.456	0.281	-0.175
$V_+(\partial\varphi/\partial V_+)$	-0.402	-0.730	-0.328
$W_+(\partial\varphi/\partial W_+)$	-0.298	-0.109	0.189
$V_-(\partial\varphi/\partial V_-)$	-0.043	0.124	0.167
$W_-(\partial\varphi/\partial W_-)$	0.690	0.475	-0.215
$(\partial\varphi/\partial a)_{\rho_0}$	0.034	0.173	
$(\partial\varphi/\partial a)_A$	0.098	0.231	
$(\partial\varphi/\partial R)_{\rho_0}$	-0.029	-0.052	
$(\partial\varphi/\partial R)_A$	0.030	0.057	0.027

the Woods-Saxon potential for a given number of nucleons, keeping the volume integral of the potential constant. The fact that $(\partial\varphi/\partial a)_A$ is small guarantees that the value of $\Delta\varphi$ will be relatively independent of the nuclear model chosen.

This model-independence of $\Delta\varphi$ is a consequence of the "transparency" of nuclear matter. That is, in carbon the largest regenerated K_1 amplitude is found at the thickest part of the nucleus, and even for gold the central K_1 amplitude is still about 40% of the maximum value. Regeneration occurs throughout the volume of the nucleus. So we find that the relevant quantities of Table I may even be derived approximately using a uniform disk of nuclear matter of thickness = radius = R, without any integrations.

Examination of Table I and the probable errors involved leads to the conclusion that the real K^--nuclear potential is the only parameter that could conceivably make a crucial change in $\Delta\varphi$. For V_- we find published values of -60 Mev at 240 Mev/c,[13] and -30 Mev at 350 Mev/c;[14] no errors are quoted. If we extrapolate V_- to a value at 565 Mev/c of -22.5 Mev ±50%, we find

$$\Delta\varphi = -0.17 \pm 0.11,$$

where the error includes the effect of uncertainties in all relevant parameters.

We must, however, consider the possibility that V_- is not within these limits. Clearly, from Table I, if $|V_-| < 22.5$ Mev, then $|\Delta\varphi|$ is even larger than 0.17, so such values of V_- present no problem. What is more important is the behavior of $\Delta\varphi$ for large values of $|V_-|$. Investigation reveals that $\Delta\varphi$ never becomes positive no matter how large $|V_-|$ gets, but instead reaches a maximum of

-0.024 for $V_- = -60$ Mev. However, because of the errors in other quantities, $\Delta\varphi$ becomes consistent with zero at about $V_- = W_-$. That the real part of the K^- potential should be as big as the imaginary part, though it seems improbable in the light of present experimental information, cannot be definitely excluded.

K^--neutron and K^--proton scattering data can also be used in evaluating V_-. From reference 10 we have $V_-/W_- = \mathrm{Re}f_-^0/\mathrm{Im}f_-^0$, where V_- and W_- apply to the nucleus as before but where f_-^0 now applies to the individual nucleons. Data on K^--p scattering at[15] 400 Mev/c appear inconsistent with $\mathrm{Re}f_-^0 \geq \mathrm{Im}f_-^0$, and only a sharp decrease in inelastic cross section with increasing energy could make $\mathrm{Re}f_-^0 = \mathrm{Im}f_-^0$ at 565 Mev/c. This, too, appears unlikely but cannot be excluded. No similar data on neutrons have been published.

Thus we may conclude that the inequality $|V_-| < |W_-|$ is strongly supported but not established beyond doubt. An analysis of K^--p and K^--n elastic scattering data in the neighborhood of 600 Mev/c would easily clarify this point. One need only demonstrate that the forward K^--nucleon elastic scattering differential cross section is less than twice the optical theorem value. This must be done before a Kobzarev-Okun' experiment is undertaken.

There appear to be no other obstacles to the experiment, and, indeed, the effect predicted should be rather easy to observe in a hydrogen bubble chamber. If $\Delta\varphi = -0.17$, then the ratio,

$$\frac{\text{transmission component, gold first}}{\text{transmission component, carbon first}} \approx \frac{1 \pm \Delta\varphi}{1 \mp \Delta\varphi}$$

$$\approx 1.4 \text{ or } 0.7,$$

changes by a factor of two depending on the sign of the mass difference. (If, as anticipated,[16] K_2 is heavier than K_1, then the ratio takes the larger value.) The diffraction-regenerated K_1 component, on the other hand, is insensitive to mass-difference effects and may be used for normalization, as pointed out by Good,[4] thus suppressing the effect of uncertainties in K_2 flux and nuclear parameters.

We wish to thank J. Meyer for his encouragement and advice. This work was supported by the Commissariat à l'Energie Atomique.

Note added in proof. Ferro-Luzzi, Tripp, and Watson[17] have published K^--proton data which verify that $|\mathrm{Re}f^0| < |\mathrm{Im}f^0|$ at 513 Mev/c. Also they find that the inelastic cross section for the $T=1$ state is greater than that for $T=0$; so the above conclusion holds for the neutron as well. The sign of $\Delta\varphi$ is therefore established.

---

[1]R. H. Good, R. P. Matsen, F. Muller, O. Piccioni, W. M. Powell, H. S. White, W. B. Fowler, and R. W. Birge, Phys. Rev. 124, 1223 (1961).

[2]I. Yu. Kobzarev and L. B. Okun', J. Exptl. Theoret. Phys. (U.S.S.R.) 39, 605 (1960) [translation: Soviet Phys.–JETP 12, 426 (1961)].

[3]A. Pais and O. Piccioni, Phys Rev. 100, 1487 (1955).

[4]M. L. Good, Phys. Rev. 110, 550 (1958).

[5]S. Fernbach, R. Serber, and T. B. Taylor, Phys. Rev. 75, 1352 (1949).

[6]The materials used should have largest possible number N of atoms per cm^3, for two reasons: (1) to increase the yield of transmission-regenerated K_1's, which is proportional to N^2; and (2) to decrease the relative size of the background of diffraction-regenerated K_1's, which is proportional only to N.

[7]R. D. Woods and D. S. Saxon, Phys. Rev. 95, 577 (1954).

[8]B. Sechi-Zorn and G. T. Zorn, Phys. Rev. 120, 1898 (1960).

[9]L. R. B. Elton, Nuclear Sizes (Oxford University Press, New York, 1961).

[10]R. Lipperheide and D. S. Saxon, Phys. Rev. 120, 1458 (1960); M. A. Melkanoff, D. J. Prowse, D. H. Stork, and H. K. Ticho, Phys. Rev. Letters 5, 108 (1960).

[11]V. Cook, D. Keefe, L. T. Kerth, P. G. Murphy, W. A. Wenzel, and T. F. Zipf, Phys. Rev. Letters 7, 182 (1961).

[12]L. T. Kerth, Revs. Modern Phys. 33, 389 (1961).

[13]R. D. Hill, J. H. Hetherington, and D. G. Hall, Phys. Rev. 122, 267 (1961).

[14]M. Melkanoff, D. J. Prowse, and D. H. Stork, Phys. Rev. Letters 4, 183 (1960); A. D. Martin, Nuovo cimento 21, 88 (1961).

[15]L. Alvarez, Ninth Annual International Conference on High-Energy Physics, Kiev, 1959 (Academy of Science U.S.S.R., Moscow, 1960).

[16]V. Berger and E. Kazes, Phys. Rev. 124, 279 (1961); J. Nilsson, Nuovo cimento 22, 414 (1961).

[17]M. Ferro-Luzzi, R. D. Tripp, and M. B. Watson, Phys. Rev. Letters 8, 28 (1962).