KN scattering in the cloudy bag model: s, p, and d waves

E. A. Veit
Departamento de Fisica, Universidade Federal do Rio Grande do Sul, Rua Luiz Englert, S/N, 90000, Porto Alegre, Brasil

A. W. Thomas
Department of Physics, University of Adelaide, South Australia 5001, Australia

B. K. Jennings
TRIUMF, 4004 Wesbrook Mall, Vancouver, British Columbia, Canada V6T 2A3

(Received 16 November 1984)

s-, p-, and d-wave KN phase shifts are calculated with the cloudy bag model (CBM). The results are in qualitative agreement with phase-shift analysis, except in those partial waves where exotic resonances are claimed to exist. However it seems that it is possible to get good agreement for these waves by just modifying the CBM potential, without including explicitly exotic states.

I. INTRODUCTION

In recent years much progress has been made in the understanding of low-energy hadronic properties through the use of chiral bag models.[1–9] In spite of partial successes this program still remains controversial, with many issues, such as the size and nature of the bag, still being debated. In order to help resolve these issues, it is important to confront as many observables as possible.

Among the properties already investigated in some detail are magnetic moments and charge radii[10–14] and the axial-vector form factor of the nucleon.[14–18] Low-energy pion-nucleon scattering[12,19–21] has also been studied with the strongest emphasis on the $P33$ channel.[12] The other channels have received much less attention although the s wave in particular seems to be yielding new information.[9,20,21] There has also been work on photoproduction[22] and radiative decay.[23]

Chiral bag models have been extended to SU(3) symmetry to also include the strange particles. Thus corrections to hyperon magnetic moments arising from kaon loops have been investigated and their relative contribution has been found to be small in comparison with the pion contribution.[24,25]

In the previous work we turn our attention to KN ($S=1$) scattering. In a previous investigation of $\overline{K}N$ scattering[26] we found that the $\Lambda^*(1405)$ resonance is predominantly a bound state. That problem was complicated by having within a 100-MeV energy range two thresholds, a strong resonance, and large background terms. The motivation of the present work is to check the SU(3) cloudy bag model in a region where there are no complicating strong resonances. However, as we shall see, even the weak resonances can cause trouble.

The present work is part of a systematic study of meson-nucleon scattering. As already noted we have previously studied the $\overline{K}N$ system,[26] this work is concerned with KN, and in the future we will return to πN. The scattering problem, in contrast to magnetic moments, permits the study of the momentum dependence of observables and enables in particular the assessment of the region beyond which the model with point mesons and sharp surfaces breaks down.

Since quarks have negative strangeness the $S=+1$ sector does not have three quark states. However the Particle Data Group tables[27] list three Z^* resonances (all one star) in the energy range of interest. The question then arises as to whether the structures seen are due to four-quark—one-antiquark effects or more conventional meson-baryon potential effects if indeed the two are actually different.

The layout of the present work is as follows. In Sec. II we present the model in a condensed manner, since it has been discussed in considerable detail in Ref. 26. The results are discussed and compared with both phase-shift analysis and the predictions of a one-meson-exchange potential in Sec. III. In Sec. IV we give our conclusions.

II. THE MODEL

For our description of KN scattering we use the cloudy bag model[12] (CBM) in the volume-coupling version.[7–9,26,28] To order ϕ^2 the Lagrangian density is

$$\mathscr{L}=(i\bar{q}\partial q-B)\theta_v-\tfrac{1}{2}\bar{q}q\delta_s+\tfrac{1}{2}[\partial_\mu\boldsymbol{\phi}]^2-\tfrac{1}{2}m^2\boldsymbol{\phi}^2+\frac{\theta_v}{2f}\bar{q}\gamma^\mu\gamma_5\boldsymbol{\lambda}\cdot\partial_\mu\boldsymbol{\phi}q-\frac{\theta_v}{(2f)^2}\bar{q}\gamma^\mu\boldsymbol{\lambda}\cdot(\boldsymbol{\phi}\times\partial_\mu\boldsymbol{\phi})q\ , \quad (2.1)$$

where q and $\boldsymbol{\phi}$ are the quark and meson-octet fields, B the bag constant, and $\boldsymbol{\lambda}$ the SU(3) matrices of Gell-Mann. The function θ_v is one inside the bag and zero outside, while δ_s is a surface δ function. For a static, spherical bag (as we assume) these functions reduce to $\theta(R-r)$ and $\delta(R-r)$. The SU(3) cross product is

$$(\boldsymbol{\phi}\times\partial_\mu\boldsymbol{\phi})_a=\sum_{bc}\phi_b\partial_\mu\phi_c f_{abc}\ , \quad (2.2)$$

where f_{abc} are the SU(3) structure constants.[29]

Note that it is essential that the mesons be allowed inside the bag in order for the present model to work: First, because the dominant coupling term in Eq. (2.1) is only present when the mesons are inside. Second, because exclusion of the mesons from the bag generates a large and spurious scattering from an empty bag. More will be said on this later (see also Ref. 26). Allowing the mesons into the bag can however cause conceptual and overcounting problems. Presumably the mesons have a $q\bar{q}$ structure and by letting them into the bag we are mocking up the $q^4\bar{q}$ states. Thus one can think of processes such as a meson which disassociates into a $q\bar{q}$ pair at the edge of the bag and recombines as a meson at the far side leaving the bag. Such processes involving $q^4\bar{q}$ are to some extent implicitly included by allowing the mesons inside the bag. As a consequence some care must be taken to avoid overcounting if one wants to include $q^4\bar{q}$ state explicitly. From the above discussion one expects mesons to have a different mass inside the bag than outside. This would introduce an additional term in the Lagrangian:

$$\mathscr{L}_{\delta m}=\tfrac{1}{2}(\delta m)^2\phi^2\theta_v\ , \tag{2.3}$$

and hence a mass inside the bag of

$$m_{\text{inside}}=[m_K{}^2+(\delta m)^2]^{1/2}\ . \tag{2.4}$$

As we will see the experimental data indicates that δm is quite small at least for the radii we consider ($R=1$ fm) and hence the mesons look similar both inside and outside the bag.

Some processes contributing to the scattering are shown in Fig. 1. There are three distinct terms: the contact term, the crossed meson lines, and the mass term of Eq. (2.3). We proceed by calculating the matrix elements of the interaction Hamiltonian between baryon states and then solve coupled Lippmann-Schwinger equations for the KN and $K\Delta$ channels. The K^*N channel is more problematic. Its inclusion would require additional assumptions in order to determine the necessary coupling constants. The K^* is also quite heavy, almost twice the mass of kaon and nearly as heavy as the nucleon. Since one of the reasons for singling out the pseudoscalar mesons is their light mass it is not clear if the vector particles should also be treated as elementary fields or as bags. In any case the K^* would be expected to be important only at the upper end of our energy range and we have not included it.

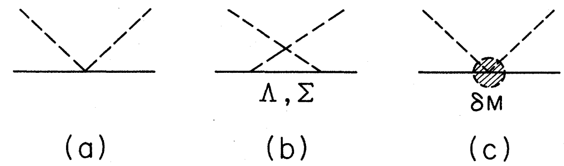

FIG. 1. Born terms of the KN scattering amplitude, (a) contact term, (b) crossed meson lines, and (c) mass term. The solid lines represent baryons, and dashed ones kaons.

We begin by presenting the potential generated by the contact piece of the interaction Hamiltonian, namely,

$$v^c_{\alpha\beta}=\left\langle\alpha\left|\int d^3x\frac{\theta_v}{(2f)^2}\bar{q}\gamma^\mu\boldsymbol{\lambda}\cdot(\boldsymbol{\phi}x\partial_\mu\boldsymbol{\phi})q\right|\beta\right\rangle\ , \tag{2.5}$$

where α and β stand for the KN or $K\Delta$ channels. Following Ref. 26 this matrix element is evaluated using the MIT bag wave functions and the Fourier transform of the meson field,

$$\phi(\mathbf{x})=\frac{1}{(2\pi)^{3/2}}\int\frac{d^3k}{\sqrt{2\omega_k}}(a_k e^{i\mathbf{k}\cdot\mathbf{x}}+a_k^\dagger e^{-i\mathbf{k}\cdot\mathbf{x}})\ , \tag{2.6}$$

where $a_k^\dagger$ (a_k) represents the kaon creation (annihilation) operator. Expanding the plane waves of the meson field in the standard form

$$e^{i\mathbf{k}\cdot\mathbf{x}}=4\pi\sum_{lm}(i)^l j_l(kx)Y^*_{lm}(\hat{\mathbf{k}})Y_{lm}(\hat{\mathbf{x}})\ , \tag{2.7}$$

it is straightforward to get the contribution from the time piece of ∂_μ in the form

$$v^{\text{TC}}_{\alpha\beta}(k,k')=\sum_I\frac{\lambda^{t,I}_{\alpha\beta}}{2f^2}\frac{[\omega_M(k)+\omega_{M'}(k')]}{2\pi^2[2\omega_M(k)2\omega_{M'}(k')]^{1/2}}C^{i_Bi_Mi}_{I_BI_MI}C^{i_{B'}i_{M'}i}_{I_{B'}I_{M'}I}$$
$$\times\sum_{lm}Y^*_{lm}(\hat{\mathbf{k}}')Y_{lm}(\hat{\mathbf{k}})\int_0^R dx\,x^2N_s{}^2[j_0{}^2(\omega_sx)+j_1{}^2(\omega_sx)]\,j_l(kx)j_l(k'x)\ , \tag{2.8}$$

where $\lambda^{t,I}_{\alpha\beta}$ is the coupling constant for the $\alpha\beta$ vertex with total isospin I given in Table I. The isospin of the baryon (meson) is denoted by $I_{B(M)}$ and its third component by $i_{B(M)}$. The energy of the $1s$ quark state is $\omega_s\simeq 2.04/R$. While s-wave scattering originates exclusively in the time piece of the contact term ($\propto\gamma^0$), $l>0$ scattering requires the spatial piece of v^c ($\propto\gamma$), hence for p and d waves, it is necessary to also evaluate the remaining piece of v^c [Eq. (2.5)].

Using the same expansion in partial waves and standard angular-momentum-decomposition techniques, the spatial piece can be written as (Ref. 28 contains the corresponding expression at the quark level)

$$v^{\text{SO}}_{\alpha\beta}(\mathbf{k},\mathbf{k}')=\sum_I\frac{\lambda^{\text{SO},I}_{\alpha\beta}}{2f^2}\frac{1}{2\pi^2[2\omega_M(k)2\omega_{M'}(k')]^{1/2}}C^{i_Bi_Mi}_{I_BI_MI}C^{i_{B'}i_{M'}i}_{I_{B'}I_{M'}I}$$
$$\times\sum_{JM}\sum_{l,m,m'}C^{m s_B M}_{l\,S_B J}C^{m' s_{B'} M}_{l\,S_{B'} J}Y^*_{lm}(\hat{\mathbf{k}}')Y_{lm}(\hat{\mathbf{k}})(-2)[6l(l+1)]^{1/2}(2l+1)^{1/2}$$
$$\times(-1)^{J+l+1/2}\begin{Bmatrix}S_B & S_{b'} & 1\\ l & l & J\end{Bmatrix}\int_0^R dx\,x^2\left[2N_s{}^2\frac{1}{x}j_0(\omega_sx)j_1(\omega_sx)\right]j_l(kx)j_l(k'x)\ . \tag{2.9}$$

Here the curly bracket represents 6-j coefficients while $\lambda_{\alpha\beta}^{SO,I}$ are coupling constants and their values are given in Table I. Note that the time piece of v_c gives a central potential v^{TC}, while the spatial piece yields a spin-orbit one v^{SO}.

We next turn to the crossed graph, Fig. 1(b). The procedure is to calculate the Yukawa vertices generated by

$$H_s=\int d^3x\left[-\frac{\theta_v}{2f}\right]\bar{q}\gamma^\mu\gamma_5\boldsymbol{\lambda}\cdot q\partial_\mu\phi \tag{2.10}$$

and then combine them to get the crossed term. It is easier to evaluate the matrix elements of this operator using the fact that for massless quarks it may be written as[26,28]

$$H_s=\int d^3x\left[\frac{i}{2f}\bar{q}\gamma_5\boldsymbol{\lambda}\cdot q\phi\delta_s-\frac{\theta_v}{2f}\partial_0(\bar{q}\gamma^0\gamma_5\boldsymbol{\lambda}\cdot q\phi)\right]. \tag{2.11}$$

For baryons with all quarks in the same s state the second term on the right-hand side of Eq. (2.11) does not contribute, and (as already pointed out[26,28]) the volume-coupling form factor of the CBM is identical to the surface one. [It is given by the first term of Eq. (2.11).] Hence, the vertex function generated by H_s has the well-known form[12]

$$v_{BM,B_i}(k)=\sum_I\frac{\lambda_{BM,B_i}}{2f}\frac{1}{[(2\pi)^3 2\omega(k)]^{1/2}}C_{I_B I_M I}^{i_B i_M i}\delta_{I,I_{B_i}}\sum_{JM}\left[\frac{4\pi}{3}\right]^{1/2}Y_{lm}^*(\hat{\mathbf{k}})C_{S_B 1 J}^{s_B m M}\delta_{J,S_{B_i}}\mathscr{F}_{BM,B_i}(k) \tag{2.12}$$

with

$$\mathscr{F}_{BM,B_i}(k)=i\left[\frac{\omega_s R}{\omega_s R-1}\right]\frac{1}{R}j_1(kR)\,. \tag{2.13}$$

Here the baryon-meson channel (BM) couples to a pure quark state B_i with no kaon around.

Knowing the vertex function and coupling the appropriate angular momenta and isospins, we get the following expressions for the potential given by the crossed graph:

$$\begin{aligned}v_{\alpha\beta}^x(\mathbf{k},\mathbf{k}';E)=&\sum_I\frac{1}{3}\frac{\lambda_{B_iM',B}}{2f}\frac{\lambda_{B_iM,B'}}{2f}\frac{1}{2\pi^2[2\omega(k)2\omega(k')]^{1/2}}C_{I_B I_M I}^{i_B i_M i}C_{I_B I_{M'} I}^{i_B i_{M'} i}\\ &\times\sum_{J,M,m,m'}C_{S_B 1 J}^{s_B m M}C_{S_{B'} 1 J}^{s_{B'} m' M}Y_{1m'}^*(\hat{\mathbf{k}}')Y_{1m}(\hat{\mathbf{k}})(-1)^{S_{B'}+S_B+I_B+I_{B'}+I_M+I_{M'}}\\ &\times(2S_B+1)^{1/2}(2S_{B'}+1)^{1/2}(2I_B+1)^{1/2}(2I_{B'}+1)^{1/2}\begin{Bmatrix}I_M & I_B & I\\ I_{M'} & I_{B'} & I_{B_i}\end{Bmatrix}\begin{Bmatrix}S_B & 1 & J\\ S_{B'} & 1 & S_{B_i}\end{Bmatrix}\\ &\times\mathscr{F}_{B_iM,B'}^*(k)\frac{1}{E-M_{B_i}-\omega_M(k)-\omega_{M'}(k')}\mathscr{F}_{B_iM,B}(k)\,.\end{aligned} \tag{2.14}$$

Again α and β denote the KN or $K\Delta$ channels. B_i is an intermediate baryon, in the present calculation Δ or Σ, and the function $\mathscr{F}_{B_i,MB'}$ is given in Eq. (2.13). The coupling constants $\lambda_{B_i,M,B'}$ are given in Table II. In Eq. (2.14) we have neglected the recoil energy of the intermediate baryon. With this approximation the crossed term only contributes to p waves.

The mass of the strange quark enters in two distinctly different ways. First it contributes to the mass of the kaon, Σ and Λ and its effect is taken into account by using the physical masses for these particles. Second it changes the form factors for the crossed graphs [Fig. 1(b)]. Here we expect the effect to be small the same as in $\bar{K}N$ scattering[26] and we neglect its effects. The crossed graphs in any event give a rather small contribution.

There remains the potential corresponding to the mass term [Eq. (2.3)]. Its decomposition in partial waves gives

$$v_{\alpha\beta}^{\delta m}=\frac{(\delta m)^2R^2}{\pi(\omega_k\omega_{k'})^{1/2}}\sum_{lm}\int dx\,x^2 j_l(kx)j_l(k'x)Y_{lm}^*(\hat{\mathbf{k}}')Y_{lm}(\mathbf{k}')\,. \tag{2.15}$$

III. RESULTS AND DISCUSSION

In this section we present and discuss our numerical results. The first question to settle is what value to use for f. Of course, for strict $SU(3)_F$ symmetry $f_\pi=f_K$ while experimentally $f_K=112$ MeV while $f_\pi=93$ MeV. Since we do not know how the symmetry is broken we use values intermediate between 93 and 112 MeV. As discussed in Ref. 26, the value of f is renormalized somewhat. In Fig. 2 we show the isospin 1 scattering length for two values of f and a range of radii, assuming $\delta m=0$. With a radius of about 1 fm and f the order 100 MeV our

TABLE I. The coupling constant for $\overline{KN}$ scattering in the contact term with isospin $I=0$ and $I=1$ [Eqs. (2.8) and (2.9)].

	$\lambda^{t,I}_{\alpha\beta}$				$\lambda^{\mathrm{SO},I}_{\alpha\beta}$			
I	0		1		0		1	
$\alpha \backslash \beta$	$\overline{K}N$	$\overline{K}\Delta$	$\overline{K}N$	$\overline{K}\Delta$	$\overline{K}N$	$\overline{K}\Delta$	$\overline{K}N$	$\overline{K}\Delta$
$\overline{K}N$	0	0	1	0	-1	0	$\frac{2}{3}$	$-2\sqrt{2}/3$
$\overline{K}\Delta$	0	0	0	$-\frac{1}{2}$	0	0	$-2\sqrt{2}/3$	$\sqrt{10}/6$

results show remarkable agreement with the data. In the absence of a mass term [Eq. (2.3)], the $I=0$ scattering length is zero with the $SU(3)_F$ couplings (Table II). However, the K^+p and K^+n channels renormalize slightly differently and this generates a small $I=0$ coupling[26] ($\simeq 5\%$ of that for $I=1$). This yields a small scattering length $\simeq -0.01$ fm. (The experimentally allowed range is $-0.11 \le a_0 \le 0.04$ fm.) Thus we see that our model describes the scattering lengths quite well. (We have discussed the scattering lengths previously[26] but we include them again for completeness, as well as to justify our choice for f.)

Up to now we have not included the contribution from the mass term. Let us turn to the question of how large δm should be. We see from the scattering lengths that it must have a rather small effect. This is in contrast to pion-nucleon scattering where a phenomenological repulsion may be used to bring about agreement for the πN scattering lengths.[20,21] There it was necessary to take δm [Eq. (2.4)] to be ~ 92 MeV corresponding to an increase of ~ 30 MeV in m_π. A similar shift $\delta m \sim 92$ MeV increases the kaon mass only by ~ 8 MeV. This decreases the $\overline{KN}$ scattering lengths only by 3%. Hence the agreement with the experiment is roughly as shown in Fig. 2 and both the pion and kaon results are consistent with $\delta m \sim 92$ MeV.

Turning our attention to finite momentum transfer, we compare the phase shifts this model gives with phase shift analysis. Unfortunately the low-energy $\overline{KN}$ data are still poor (another reminder of the need for a kaon factory), giving rise to a few quite different phase-shift analyses (see, for example, Ref. 31). Here we present only the more recent analysis of Arndt and Roper,[32] Corden *et al.*,[33] and Hashimoto.[34] In some cases we compare our results also with those from a meson-exchange calculations.[31] The reader who is particularly interested in this comparison should compare all our results with those of Davis *et al.*[31]

TABLE II. The coupling constant for $\overline{KN}$ scattering in the crossed graph [$\lambda_{B_iM,B'}$ of Eq. (2.14)].

$B' \backslash B_iM$	$K\Sigma$	$K\Delta$
N	-1	-3
Δ	$-2\sqrt{2}$	0

The $I=1$ s-wave phase shift is shown as a function of energy in Fig. 3(a). Our results and those of the meson-exchange model are rather similar. Unfortunately both tend to deviate from the results of the phase-shift analysis at $E_{\mathrm{c.m.}} \simeq 1700$ MeV. This is a rather general feature of our results and we will restrict most of our further discussion to this low-energy range. It is not surprising that our model breaks down as the energy increases since we have assumed a structureless meson and a sharp bag surface. The breakdown appears to occur when the center of mass momentum reaches about 2–2.5 fm^{-1} corresponding to a distance of about 0.5 fm. In Fig. 3(b) we show the $I=0$ s-wave phase shift. Both our results and the somewhat uncertain phase-shift analysis are rather small.

The p-wave results are shown in Fig. 4. The agreement for the $P11$ and $P03$ waves is quite good. However our model does poorly in the $P01$ and $P13$ channels. These are just the channels in which evidence for exotic resonances has been claimed: the one-star states[27] $Z_0(1780)$ and $Z_1(1900)$. One possibility is that the disagreement is evidence for exotic $q^4\overline{q}$ states. Another possibility is that we deal with a potential effect which our model is not able to account for. The largest effect of the crossed meson lines is in the $P13$ wave where it decreases the phase shift by 30% at $E=1660$ MeV.

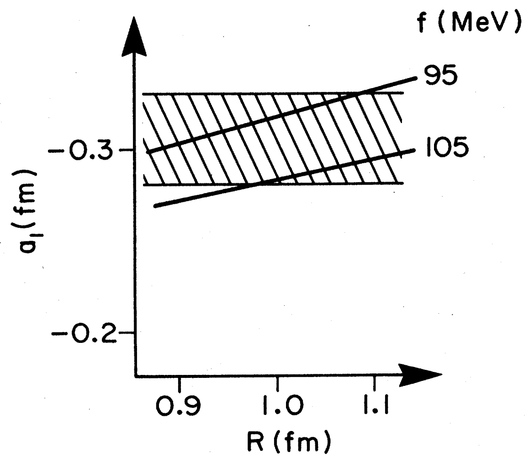

FIG. 2. $I=1$ $\overline{KN}$ scattering length against the bag radius for different values of f ($\delta m=0$). The dashed region indicates the range of experimental results. $a_1=-0.33$ fm is the more recent one (Ref. 30).

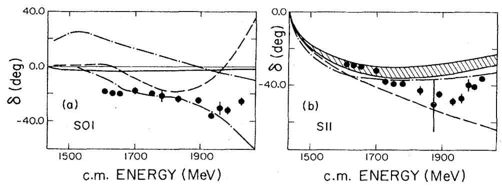

FIG. 3. Phase shifts for (a) $S01$ and (b) $S11$ partial waves. Our results are given by the solid curve for the $S01$ partial wave and by the dashed region (95 MeV $\leq f \leq$ 105 MeV) for $S11$. The dots are Hashimoto's phase-shift analysis (Ref. 34), while the dashed curves are the phase-shift analyses of Arndt and Ropa (Ref. 32) for $I=1$ and Corden *et al.* (Ref. 33) for $I=0$. The dash-dot curves are the meson-exchange-model results of Davis, Cottingham, and Alcock (Ref. 31).

In Fig. 5 we show the $P13$ partial wave in a larger energy range. As well as the CBM [in Fig. 4(d)] and the meson-exchange result,[31] there is a curve where the spin-orbit term is arbitrarily multiplied by 3. This is seen to be qualitatively similar to the data. The coupling to the $K\Delta$ channel appears to play a large role in getting the bump in the phase shift. Increasing the spin-orbit piece by a factor 3 also gives a dramatic improvement in the $P01$ wave and only slightly worsens the agreement in the other two channels.

Additional spin-orbit terms will arise from boosting the bag due to the spin rotation obtained in the Lorentz-boost operator. A simple estimate gives a 50% increase in the spin-orbit force from this effect. This would change none of our conclusions and because of general uncertainties in boosting the bag we have not explicitly included the effect.

The d-wave phase shifts are shown in Fig. 6. Here perhaps more than with the lower partial wave we are plagued with uncertainties in the experimental data. Anyway, the results obtained with the CBM are reasonable. Again for the $D03$ wave where an increase in the spin-orbit term considerably improves the agreement, there is claimed to be an exotic resonance, the $Z_0(1865)$ (Ref. 27). This resonance is also claimed to be associated with the K^*N threshold which we have not included.

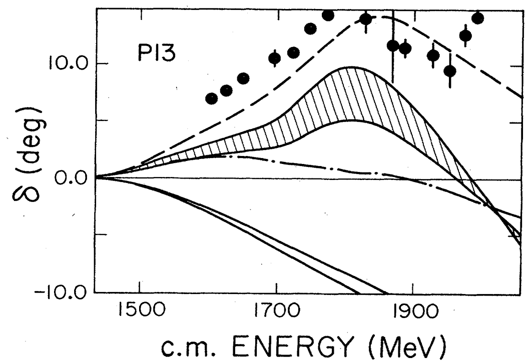

FIG. 5. Phase shift for the $P13$ partial wave. The solid curves are the CBM result ($f=95$ MeV and $f=105$ MeV) while the dashed region is our results with three times the spin-orbit potential given by the CBM (95 MeV $\leq f \leq$ 105 MeV). The dots are Hashimoto's phase-shift analysis while the dashed curve is the result from Arndt and Roper (Ref. 32). The dash-dot curve is the meson-exchange result of Davis, Cottingham, and Alcock (Ref. 31).

IV. CONCLUSION

The cloudy bag model has been used to calculate the s-, p-, and d-wave KN phase shifts. The comparison with phase-shift analysis shows that the CBM gives results of the same quality as the one-meson-exchange model. For most of the partial waves this means good qualitative agreement. The model fails where exotic resonances have been postulated ($P01$, $P13$, and $D03$ partial waves). We could have introduced a pole term to describe these "resonances." However, we feel that by including it phenomenologically we would not clarify the problem. In the $\bar{K}N$ system the contact term is responsible for most of the bump associated with the $\Lambda^*(1405)$. Here it does not reproduce the bumps shown in the $P01$, $P03$, and $D03$ phase shifts. However, by increasing its spin-orbit piece by a factor of 3 it is possible to get a strong enhancement in the phase shifts, indicating that it is very possible that the claimed exotic resonances are fairly trivial potential effects.

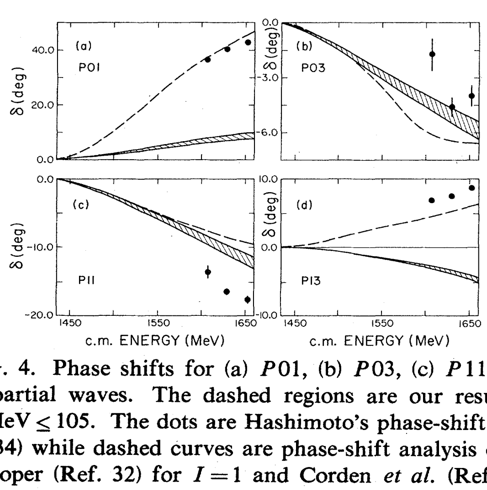

FIG. 4. Phase shifts for (a) $P01$, (b) $P03$, (c) $P11$, and (d) $P13$ partial waves. The dashed regions are our results with $95 \leq \text{MeV} \leq 105$. The dots are Hashimoto's phase-shift analyses (Ref. 34) while dashed curves are phase-shift analysis of Arndt and Roper (Ref. 32) for $I=1$ and Corden *et al.* (Ref. 33) for $I=0$.

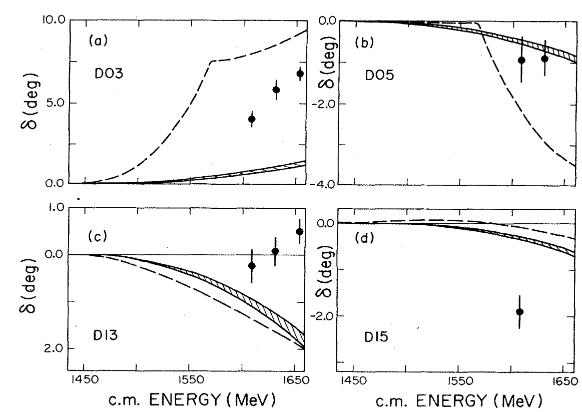

FIG. 6. Phase shifts for the (a) $D03$, (b) $D05$, (c) $D13$, and (d) $D15$ partial waves. The convention is the same as in Fig. 4.

Our results show that a chiral bag model with a large bag radius and mesons allowed inside the bag is a good starting point to describe low energies meson-baryon scattering. As the momentum increases the model shows signs of breaking down at a center of mass momentum of $\sim 2\ \text{fm}^{-1}$.

In summary, the CBM describes quite well most of the *s*, *p*, and *d* waves in *KN* scattering. With respect to the nature of the $Z_0(1730)$, $Z_1(1900)$, and $Z_0(1865)$ (one-star states[27]), our results show that they may be just potential effects. Nevertheless the possibility that there are exotic $(q^4\bar{q})$ states is not ruled out.

ACKNOWLEDGMENTS

It is a pleasure to acknowledge A. S. Rinat for a critical reading of the manuscript, O. Maxwell, N. De Takacsy, R. H. Landau, G. Walker, and R. C. Barrett for stimulating and useful discussions. One of the authors (E.A.V.) would like to thank the hospitality at TRIUMF where most of this work has been done. Natural Sciences and Engineering Research Council (Canada), Conselho Nacional de Pesquisas do Brasil (CNPq) and Financiadora de Estudos e Projectos (FINEP) (Brazil), and the University of Adelaide are thanked for financial support.

[1] T. Inoue and T. Maskawa, Prog. Theor. Phys. **54**, 1833 (1975).

[2] A. Chodos and C. B. Thorn, Phys. Rev. D **12**, 2733 (1975).

[3] G. E. Brown and M. Rho, Phys. Lett. **82B**, 177 (1979).

[4] R. L. Jaffe, in *Pointlike Structures Inside and Outside Hadrons*, proceedings of the Seventeenth International School of Nuclear Physics, Erice, 1979, edited by A. Zichichi (Plenum, New York, 1982), p. 99.

[5] G. E. Brown, in *Progress in Particle and Nuclear Physics*, edited by D. Wilkinson (Pergamon, London, 1982), p. 147.

[6] C. E. Detar and J. F. Donoghue, Ann. Rev. Nucl. Part. Sci. **33**, 235 (1983).

[7] A. W. Thomas, Adv. Nucl. Phys. **13**, 1 (1984) and references therein.

[8] A. Szymacha and S. Tatur, Z. Phys. C **7**, 311 (1981).

[9] A. W. Thomas, J. Phys. G **7**, L283 (1981).

[10] F. Myhrer, G. E. Brown, and Z. Xu, Nucl. Phys. **A362**, 317 (1981).

[11] C. E. Detar, Phys. Rev. D **24**, 752 (1981); **24**, 762 (1981).

[12] A. W. Thomas, S. Théberge, and G. A. Miller, Phys. Rev. D **24**, 216 (1981); **22**, 2838 (1980); **23**, 2106(E) (1981).

[13] S. Théberge and A. W. Thomas, Nucl. Phys. **A393**, 252 (1983).

[14] W. Weise, Erice Lectures, 1983 [Prog. Part. Nucl. Phys. (to be published)].

[15] R. Tegen, M. Schedl, and W. Weise, Phys. Lett. **125B**, 9 (1983).

[16] P. A. M. Guichon, G. A. Miller, and A. W. Thomas, Phys. Lett. **124B**, 109 (1983).

[17] B. Loiseau, N. Cottingham, and O. Maxwell (unpublished).

[18] A. S. Rinat, Phys. Lett. **134B**, 11 (1984).

[19] A. S. Rinat, Nucl. Phys. **A377**, 341 (1982).

[20] B. K. Jennings, E. A. Veit, and A. W. Thomas, Phys. Lett. **148B**, 28 (1984).

[21] A. S. Rinat (unpublished).

[22] G. Kälbermann and J. M. Eisenberg, Phys. Rev. D **28**, 66 (1983).

[23] E. J. Moniz and M. Soyeur, in *Proceedings of the Kaon Factory Workshop, Vancouver, 1979*, edited by M. K. Craddock (TRIUMF Report No. TRI-79-1, 1979); and (unpublished).

[24] P. Gonzalez and V. Vento, Nucl. Phys. **A407**, 349 (1983).

[25] P. Zenczykowski, Phys. Rev. D **29**, 577 (1984).

[26] E. A. Veit, B. K. Jennings, A. W. Thomas, and R. C. Barrett, Phys. Rev. D **31**, 1033 (1985); contribution to the 10th International Conference on Particles and Nuclei (Heidelberg, 1984) (unpublished).

[27] Particle Data Group, Rev. Mod. Phys. **56**, S1 (1984).

[28] B. K. Jennings and O. Maxwell, Nucl. Phys. **A422**, 589 (1984).

[29] See, for example, J. J. Sakurai, *Currents and Mesons* (The University of Chicago Press, Chicago, 1969).

[30] A. D. Martin, Nucl. Phys. **B179**, 33 (1981).

[31] A. C. Davis, W. N. Cottingham, and J. W. Alcock, Nucl. Phys. **B111**, 233 (1976); **B102**, 173 (1976).

[32] R. A. Arndt and L. D. Roper, scattering analyses interactive dial-in (SAID) from VPI&SU Report No. KN83-1 (unpublished).

[33] M. J. Corden, G. F. Cox, D. P. Kelsey, C. A. Lawrence, P. M. Watkins, O. Hamon, J. M. Lévy, and G. W. London, Phys. Rev. D **25**, 720 (1982).

[34] K. Hashimoto, Phys. Rev. C **29**, 1377 (1984).