e.g., the single-particle absorption or the contributions from $\Delta(1232)$. The latter are believed to be responsible for the enhancement in cross section at higher photon energies.[14] However, in my opinion, this enhancement is probably due to the neutron form factor.

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Detection of Nuclear-Bag States

C. W. Wong and K. F. Liu
Department of Physics, University of California, Los Angeles, California 90024
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We discuss the masses of nuclear bag states containing $3A$ quarks, the decay width of the deuteron bag, d^*, the appearance of dinucleon bags as resonances in nucleon-nucleon reactions, the inelastic form factor for the reaction $ed \to e'd^*$ and the differential cross section for $pd \to p'd^*$. Separation of bag signals from the background from pion production requires the detection of one or more decay nucleons.

It has been recognized for some time that the conventional nuclear theory of nucleons in nuclei relevant to the low-energy domain is inadequate in the intermediate-energy region. It should be supplemented there by additional degrees of freedom because of the presence of mesons and nucleon isobars,[1] and of quarks.[2,3] Quarks are particularly interesting because they provide a unifying picture of hadron and nuclear structures. One manifestation of quark dynamics in nuclei is the formation of "abnormal" nuclear states in which more than three quarks form a cluster or "bag" inside the nucleus.[4-6] The actual detection of these new nuclear-bag states is thus of considerable interest. We discuss in this Letter a number of questions related to the experimental detection of these nuclear bags, occurring either alone or as clusters in nuclei.

Masses.—Nuclear-bag states are so called because in the Massachusetts Institute of Technology bag model the quarks are confined in a "bag" by its surface pressure B. Model masses, calculated from Johnson's formula,[4] are given in Table I. These are not rest masses, however, but total masses including large kinetic energies of center-of-mass (c.m.) motion, which are $\simeq 0.1$–0.4 GeV for hadrons.[7] Table I also gives the rest masses after c.m. correction. Their calculation[7] requires a refit of model parameters to hadron masses, resulting in a reduction of the quark-quark interaction strength α_s and an almost complete elimination of the zero-point energy constant Z_0. Thus the original large Z_0 represents basically just this c.m. correction. It is then understandable (and reassuring) that model extrapolations for nuclear-bag masses are rather insen-

TABLE I. Nuclear-bag masses (in GeV) and bag radii (in fm) as predicted by the Massachusetts Institute of Technology bag model without and with center-of-mass correction. The u, d quarks are taken to be massless.

	State		M.I.T. model [a]		c.m. corrected model [b]		
n	S	T	M	R_{bag}	M	R_{bag}	Remarks
3	1/2	1/2	0.93	0.99	0.94	0.88	
	3/2	3/2	1.23	1.08	1.23	1.00	
6	1	0	2.15	1.31	2.18	1.24	d^* $^3S_1$
	0	1	2.23	1.32	2.25	1.25	S^* $^1S_0$
	2	1 }	2.34	1.34	2.34	1.27	$^1D_2$
	3	0 }					$^3D_3$
	1	2	2.50	1.37	2.47	1.30	
	0	3	2.79	1.42	2.71	1.34	
9	1/2	1/2	3.50	1.54	3.46	1.46	
12	0	0	4.90	1.72	4.73	1.64	

[a]Refs. 4 and 5. $B^{1/4} = 0.145$ GeV, $Z_0 = 1.84$, and $\alpha_s = 0.55$.
[b]Ref. 7. $B^{1/4} = 0.148$ GeV, $Z_0 = 0.146$, and $\alpha_s = 0.396$.

sitive to this c.m. correction. The results show that bag states begin to appear at 0.3 GeV of excitation for $n=6$, 0.65 GeV for $n=9$, and 1.0 GeV for $n=12$.

Decay widths.—It is known[8] that 20% of the "dibaryon" bag contains two baryons (in d^* or S^*, 11% is dinucleon and 9% is $\Delta\Delta$), while 80% contains two color octets (hidden colors). The width of a nonrelativistic two-body potential resonance[9] with the expected bag radius is $\Gamma_{\text{pot}} \simeq 150$ MeV. This cannot be used for the contributions from the isobaric and hidden-color components because Γ_{pot}^{-1} does not include the formation time of decay products. Indeed, Γ_{pot} for hadron decays are always larger than experimental widths, although they reproduce roughly the dependence on kinematical variables. For example, Γ_{pot} is 150 MeV for $\Delta \to N\pi$ (instead of the experimental 115 MeV), 250 MeV for $K^* \to K\pi$ (instead of 49 MeV), and 40 MeV for $\Sigma^* \to \Sigma\pi$ (instead of 4 MeV). In the absence of an actual calculation (e.g., along the line of Feynman, Kislinger, and Ravndal[10]), we shall assume in the following discussion that dibaryon bags have widths of $\simeq 50$ MeV.

Nucleon-nucleon scattering and reactions.—According to Table I (remark column), dibaryon bags with $T \leq 1$ may appear as resonances in elastic NN scattering in the partial waves $^3S_1$ (nucleon lab energy $\simeq 0.65$ GeV), $^1S_0$ ($\simeq 0.82$ GeV), $^1D_2$ and $^3D_3$ (both at $\simeq 1.04$ GeV) states. These resonances can in principle be established by showing that the appropriate Reδ rises through $\frac{1}{2}\pi$ if the inelasticity is not too large. Available phase shifts[11] are not sufficiently unique for this purpose, although certain $^1S_0$ and $^3S_1$ phase-shift solutions are not inconsistent with the expected resonance behavior with widths < 100 MeV.

Neither of the $T=1$ dinucleon bags shown in Table I corresponds to the structure seen in the spin dependence of the pp elastic cross section[12] ($\sqrt{S} = 2.25$ GeV, $\Gamma \simeq 200$ MeV, $^3F_3$ state). The structure seen in the proton polarization from deuteron photodisintegration[13] ($\sqrt{S} = 2.35$ GeV, $\Gamma \simeq 160$ MeV) could be caused in part by the $T=0$, $S=3$ bag expected at exactly the same energy. The decay of this bag is practically identical to that of the $T=0$, $S=3$ $\Delta\Delta$ resonance proposed for this structure.[14] The calculated bag mass appears more reliable than the estimated $\Delta\Delta$ masses.

Inelastic electron scattering.—We consider the reaction $ed \to e'd^*$. Single scattering dominates this reaction, d^* being formed via its 11% np component. The resulting inelastic electric form factor $G_{E,\text{inel}}^2(q^2)$ (which differs from $G_{E,\text{el}}^2$ only in the final-state wave function used[15]) as a function of the three-momentum transfer q in the c.m. frame can be calculated readily in the usual nonrelativistic treatment.[15] We use the Reid soft-core deuteron wave function (with D state)[16] in order to get good elastic form factors. For d^*, it appears sufficient for the present qualitative discussion to use an S-wave Gaussian wave function $\exp(-0.5(\vec{r}_1 - \vec{r}_2)^2/R^2)$, where $\vec{r}_i$ are the "nucleon" coordinates inside d^*. Nucleon contributions are included approximately in $G_{E,\text{inel}}^2$ and exactly[17] in $G_{E,\text{el}}^2$. The results are shown in Fig. 1(a) for unpolarized deuterons using $R/R_0 = 0.5$,

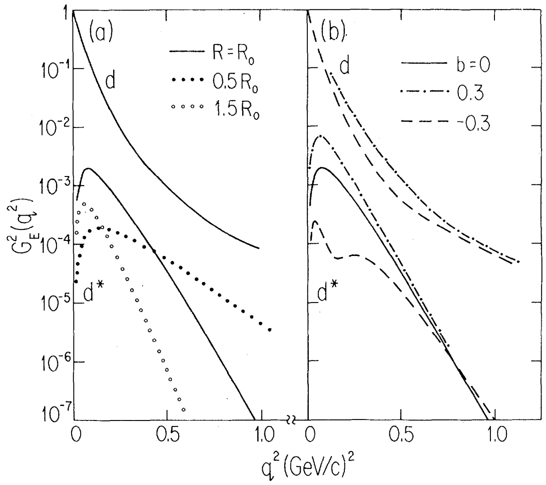

FIG. 1. Inelastic and elastic electric form factors for electron scattering from unpolarized deuterons. The results obtained by using (a) different d^* size parameter R (with $R_0 = 0.85$ fm), and (b) different admixture coefficient b of the normal nuclear state, are also shown.

1.0, and 1.5, where $R_0 = 0.85$ fm is deduced from the expected d^* size. These curves show that the d^* size can be deduced readily from $G_{E,\,\text{inel}}^2$.

An interesting complication is that the actual nuclear states are not pure states but rather the combinations

$$\psi_d = N_0(\Phi_n + b\Phi_b), \quad \psi_{d^*} = N_1(a\Phi_n + \Phi_b). \tag{1}$$

Here

$$a = -(b + n_{nb})/(1 + bn_{nb}), \tag{2}$$

where the overlap $n_{nb} = \langle \Phi_n | \Phi_b \rangle \simeq 0.16$ is not large. The solid curves in Figs. 1(a) and 1(b) show the results for $b=0$ (and $a = -n_{nb}$). Figure 1(b) also gives the results for $b = -0.3$ (broken curves) and $b = 0.3$ (dash-dotted curves). We see that the inelastic form factor will also give information on b as well.

The rather large values of b used are chosen for illustration only, although the resulting $\simeq 9\%$ admixtures of the minority configuration are not far from the 7% suggested in Ref. 8. However, the resulting large changes in the elastic form factor seen in Fig. 1(b) show that such large values of b are quite unlikely unless there are compensating changes in the nuclear wave function or in the isobar admixtures.

There is a problem with the experimental background from pion electroproduction at the first, i.e., Δ, resonance which appears at the same excitation energy. This background may be characterized by the longitudinal photoabsorption cross section for protons, which at the first resonance is[18] roughly 100 ± 30 μb for four-momentum transfers $0.1 \lesssim q_\mu^2 \lesssim 0.3$ GeV^2 and electron energies $\lesssim 1.1$ GeV. The equivalent cross section for our reaction when q_μ^2 is not too small is roughly

$$\sigma_{\text{eq}}(W) \simeq \frac{4\pi^2\alpha}{K}\frac{\Gamma/2\pi}{(W-W_R)^2 + \frac{1}{4}\Gamma^2} G_{E,\,\text{inel}}^2 \text{ mb}$$

$$\simeq 5\,\frac{\frac{1}{4}\Gamma^2}{(W-W_R)^2 + \frac{1}{4}\Gamma^2} G_{E,\,\text{inel}}^2 \text{ mb}. \tag{3}$$

Here α is the fine-structure constant, K is the equivalent photon energy ($\simeq$ electron energy loss), W is the rest mass of the recoiling object, and W_R and Γ are the mass and width of the bag resonance. At $W = W_R$ and at the maximum of $G_{E,\,\text{inel}}^2$ of Fig. 1, Eq. (3) gives roughly 10 (34, 1) μb for $b=0$ (0.3, -0.3). Thus a simple one-arm measurement does not appear promising; two spectrometers might be needed to distinguish signals from background. Fortunately these two-spectrometer experiments appear to be quite feasible.[3]

Inelastic hadronic and nuclear scatterings. —Bag states may appear in the inelastic excitation functions. We have studied the reaction $pd \to p'd^*$ at the proton lab energy $K_L = 0.8$ GeV. Here double scattering is also important, d^* being reached via all three (np, $\Delta\Delta$, and hidden-color) components. The Glauber multiple-diffraction approximation[19] is used with the double-scattering contribution calculated as if all components were nucleons. This picture is obviously very crude, but it might help in isolating interesting features. The results show that where double scattering dominates, the differential cross section is comparable to that in the elastic scattering, but that the single-scattering forward peak is greatly diminished. The results are sensitive to the mixing amplitude b (true also for elastic scattering!) and, especially at small q^2, also sensitive to the d^* size. For example, at $q^2 = 0.15$ GeV^2 we find $d\sigma/dt = 0.87$ (1.5, 0.46) mb/GeV^2 for $R/R_0 = 1.0$ (0.5, 1.5). The region $q^2 < q_{\min}^2$ ($= 0.11$ GeV^2) is kinematically inaccessible; since $q_{\min}^2$ decreases with increasing K_L, higher proton energies are more useful.

The model gives a total inelastic (elastic) cross section of 0.8 (8.0) mb for $b=0$, 0.4 (8.4) mb for $b=-0.3$, and 0.9 (8.7) mb for $b=0.3$, all calculated with $R = R_0$. The inelastic cross section for $b=0$ is 0.5 (1.0) mb for $R/R_0 = 1.5$ (0.5). These compare unfavorably with the background total cross section of $\simeq 40$ mb for pion production from deuterons. Thus single-arm experiments do not appear promising.

Two-spectrometer experiments appear to be useful, however. In one arrangement, one spectrometer can be used for the inelastic proton, limiting its energy loss (spectrometer acceptance) and sometimes even separating dibaryon resonances from baryon resonances (detector angle). The second spectrometer is then set up to detect a decay proton from the binary decay of the expected dibaryon resonance, thus identifying both protons. In another arrangement, both decay protons from a "diproton" resonance (e.g., from a ^{3}He target) can be detected. The spectrometers can often be set so that the dibaryon resonance comes from outside the kinematically allowed region of some of the baryon resonances. The remaining background in the coincidence counts as a function of the invariant mass of the diproton will be shifted down because of the undetected pion, thus separating dibaryon from baryon resonances. Finally, we note that the second spectrometer may be replaced by two particle counters.[20]

Bags might have been seen in the $\gamma d \rightarrow p_{\text{pol}} n$ experiment.[13] However, we cannot yet tell bags apart from other dibaryon resonances. Additional studies are needed to decide if the dominant hidden-color component unique to bags has observable consequences useful for direct identification. Otherwise we may have to rely on the general dynamical picture concerning where different dibaryon resonances are expected. In this connection, bags are particularly interesting because present estimates of their masses are probably reliable, and they are certainly better than present estimates[14] of other dibaryon masses. Consequently, we may first concentrate on finding resonance structures at predicted bag masses. For this purpose, coincidence experiments of the type sketched here appear promising and feasible.

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