tions, it will be important to investigate whether more sophisticated treatment of the decay of an excited projectile can explain the present data. The abrasion-ablation model however is able to give an excellent account of the present experimental data. Considering the importance of the ablation stage and the uncertainties of primary-fragment excitation energies, further investigations with projectiles of different A/Z ratios will be required to test the various models. Experiments of this type, measuring energy and isotope distribution at several energies, may eventually determine the importance of ground-state correlations in nuclei and the excitation energy deposited in the spectator nuclei during the reaction.

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Giant Dipole Resonance in ^{4}He with Noncentral Forces and Target-Recoil Corrections

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The ^{4}He giant dipole resonance is calculated with a continuum shell model which treats the center of mass correctly and includes possible noncentral components of the nucleon-nucleon interaction. The (γ,p) and (γ,n) cross sections and asymmetry coefficients agree well with the experiment. The b_2 asymmetry coefficient is shown to depend on the spin-orbit odd component of the effective nuclear force. The 1^- level positions and channel mixing are in best agreement with "solution II" of the R-matrix fit of Werntz and Meyerhof.

Because of its apparent simplicity as compared to other nuclei, the α particle should be the one system where investigation of the giant dipole resonance (GDR) is most complete. However, both experimental and theoretical ambiguities still remain.[1-5] Recent measurements[6] of the ^{3}H$(p,\gamma)^4$He asymmetry provide important new information which is necessary to further the understanding of the ^{4}He GDR. In general, asymmetry measurements always contain valuable information pertaining to the composition of the GDR. For ^{4}He, the asymmetry also provides important information on the channel mixing. As will be shown below, the mixing yields a measure of the spin-orbit odd (LSO) component of the nucleon-nucleon effective interaction.

Attempts[3] have been made to calculate the (p,γ) cross section using R-matrix parameters which were obtained from fits to particle-channel data.[7] These efforts have not given completely satisfactory results. In particular, the mixing of the $^1P_1$ and $^3P_1$ strength in two 1^- resonances is not well determined from particle data. Previous continuum shell-model calculations[8,9] have provided little additional understanding of the ^{4}He GDR. They have suffered from two major omissions: (1) In contrast to resonating-group calculations, they do not treat the center-of-mass coordinate correctly, and (2) they have not included noncentral forces in the nucleon-nucleon interaction. Both of these factors are critical in a continuum shell-model calculation for ^{4}He. This paper presents a calculation which does include these factors and describes the resulting composition of the GDR.

The present model includes 1p-1h (one-particle, one-hole) states with up to $14\hbar\omega$ excitation. The ^{3}H and ^{3}He ground states are assumed to be pure proton and neutron hole states. This was shown to be a good approximation in resonating group studies[10] of $^3\text{He}(p,p)^3\text{He}$ and $^3\text{H}(n,n)^3\text{H}$. The Coulomb and nuclear forces are two-body interactions; no additional nucleon-nucleus potential is required. Spurious center-of-mass excitations have been eliminated by the method of Philpott,[11] and therefore the calculation becomes equivalent to a corresponding resonating-group calculation. The nucleon-nucleon effective interaction is taken to be the g-matrix elements of Bertsch *et al.*[12] which were derived from realistic nucleon-nucleon potentials and have been used successfully to describe elastic and inelastic scattering in a variety of heavier systems.[12-14] This interaction is found to give excellent agreement with nucleon-channel data. The nucleon-channel results and a thorough description of techniques used in this calculation will appear in a future paper.[15]

The radiation in $^3\text{H}(p,\gamma)^4\text{He}$ has been shown to be predominantly $E1$, especially in the range $E_p = 0-8$ MeV.[3,6,16] In the case of pure $E1$ emission there are only two incident proton channels which can contribute to the capture reaction, $^3P_1$ and and $^1P_1$. The capture amplitude is commonly written as a real amplitude and phase, e.g., $\langle ^3P_1 \rangle = A_3 \exp(i\varphi_3)$. Then the a_2 coefficient of the differential cross section and the b_2 coefficient of the asymmetry may be written as[5]

$$a_2 = \tfrac{1}{2}A_3^2 - A_1^2 \tag{1}$$

and

$$b_2 = -2^{1/2}A_3A_1 \sin(\varphi_1 - \varphi_3), \tag{2}$$

where

$$A_1^2 + A_3^2 = 1.$$

Figures 1 and 2 display the results for the pure Bertsch interaction and $E1$ transitions. All cross sections have been converted to photodisintegration cross sections for comparison. Dashed curves correspond to neutron emission; solid curves correspond to proton emission. Set I assumes a pure $0s_{1/2}$ closed shell; set II gives an estimate of the effect of including ground-state correlations. Set III is the same as set I but with no center-of-mass corrections. The strength distribution for the uncorrected set does not agree with the data and this clearly demonstrates the importance of center-of-mass effects in ^{4}He. The overall agreement of the corrected calculation is very good, especially when one notes that there are no parameters to adjust.

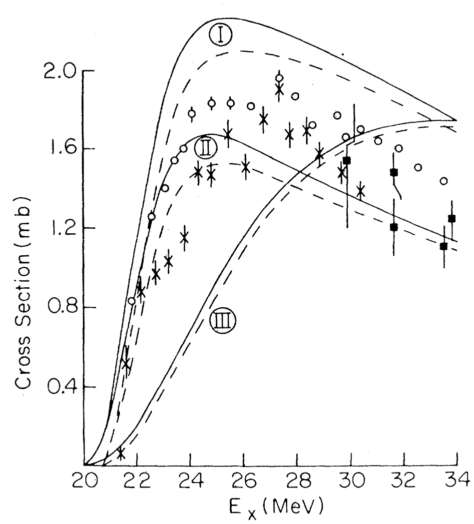

FIG. 1. Photodisintegration cross sections. Solid curves are theoretical (γ,p). Dashed curves are theoretical (γ,n). Sets I, II, and III are explained in the text. Open circles are experimental (γ,p) of Ref. 3. Crosses are experimental (γ,n) of Ref. 17. Squares are experimental (γ,n) of Ref. 18.

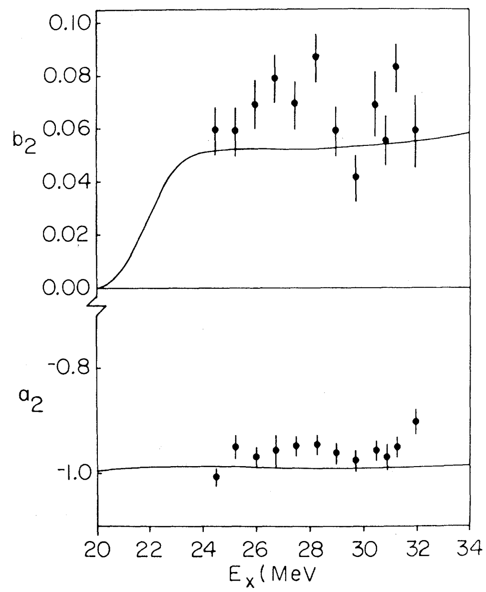

FIG. 2. Differential cross section and asymmetry coefficients. Solid curves are theoretical (p,γ). Solid circles are experimental (p,γ) of Ref. 6.

The agreement between the calculated and experimental shape of the capture cross sections indicates that the positions of the calculated 1^- resonances are about right. The locations E_R and widths Γ_R of the 1^- resonances below E_p(c.m.) $=10$ MeV are given in Table I. Because the Coulomb potential has been included where appropriate, the resonance states do not have pure isospin, but they are at least 96% pure at the surface and in the interior. The third highest 1^- state, which is mostly $T=0$, contributes to little to the $E1$ cross sections. Also shown is the position of the first 2^+ resonance. Its location and width indicate where E_2 strength may become important, and this appears to be the case experimentally[3,16] as the $E2$ cross section becomes significantly nonzero at about E_p(lab) $=8$ MeV. The lower 1^-, $T=1$ state is 95% $^3P_1$. Thus, the present calculation agrees more closely with "solution II" of Werntz and Meyerhof[3,7] which prescribes 92% of $^3P_1$ for the lowest 1^-, $T=1$ state than with "solution I" which prescribes 8%.

If ground-state correlations and the spin-dependent part of the $E1$ operator, Q_{LM}', are ignored, it is possible to demonstrate that the b_2 coefficient vanishes unless there is an LS O component in the effective interaction. If ground-state correlations and Q_{LM}' are included, the condition still holds to a good approximation. To begin, it should be pointed out that the capture amplitude

TABLE I. Total spin, parity, and energy with respect to proton thereshold, isospin probability, and nucleon spin probability for selected resonances.

J^π	E_R (MeV)	Γ_R (MeV)	P ($T=1$) (Surface)	P ($T=1$) (Interior)	P ($S=1$) (Surface)
1^-	3.57	3.82	0.95	0.97	0.95
1^-	4.23	4.66	0.98	0.99	0.06
1^-	4.94	4.88	0.04	0.04	1.00
2^+	8.81	6.80	0.01	0.01	0.00

designated by $\langle {}^{[S]}L_J\rangle$ is actually calculated from a solution to the nuclear scattering and reaction problem (including both $p+{}^3$H and $n+{}^3$He channels) which has unit incident flux in the proton channel ${}^{[S]}L_J$. The amplitude therefore contains contributions from all channels which can couple via the nuclear interaction to the designated incident channel. Since only the spin-independent $E1$ operator is considered here and the uncorrelated ^{4}He ground state has $S=0$, the $^3P_1$ capture amplitude necessarily vanishes unless the nuclear interaction contains spin-dependent terms capable of coupling the $^3P_1$ and $^1P_1$ channels. Under the assumption that the ^{3}H and ^{3}He ground states contain no nonzero orbital angular momenta, the entire coupling must arise from an interaction component which is rank 1 in spin space and is, in fact, the LSO component. If the $\langle {}^3P_1\rangle$ capture amplitude vanishes, then Eq. (2) shows that the b_2 coefficient is zero since it is proportional to A_3. The remaining term in Eq. (2), $A_1\sin(\varphi_3-\varphi_1)$, is relatively constant for variations in the LSO strength since the solution in the elastic channel is primarily determined by the stronger central components of the effective interaction. Therefore the b_2 coefficient is almost directly proportional to the LSO strength. Figure 3 shows this dependence at E_p(lab) $=6.0$ MeV. The datum point is plotted at the strength prescribed by Bertsch *et al.* and demonstrates that the prescribed strength is about correct. The same strength is also consistent with the observed $p_{1/2}$-$p_{3/2}$ splitting in ^{5}He. The calculated $0p_{1/2}$-$0p_{3/2}$ splitting is 4.5 MeV. Experimentally, the splitting is masked by the large widths of the $p_{1/2}$ and $p_{3/2}$ resonances, but the centroids are separated by about 4.3 MeV.[19]

The present calculation clearly demonstrates the necessity for both a proper treatment of the center-of-mass coordinate and inclusion of noncentral effective interactions. Specifically, there would be no asymmetry in (p,γ) without

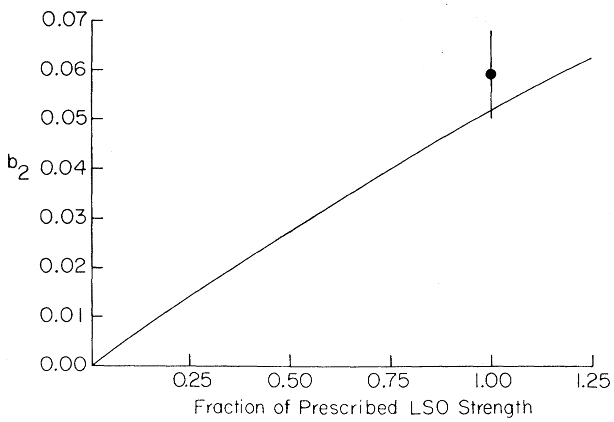

FIG. 3. Asymmetry coefficient as a function of the fraction of LS O strength at E_p(lab) = 6.0 MeV. Experimental point is from Ref. 6.

the LSO potential. When center-of-mass correction and realistic forces are employed then good agreement with the data is obtained. These factors must be included in continuum calculations before the underlying resonances of the GDR can be characterized with confidence.

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