Excitation of the Giant-Resonance Continuum with Intermediate-Energy Protons

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The angular distribution of the continuum in the reaction ^{116}Sn$(p,p')^{116}$Sn at $E_p = 800$ MeV shows a marked decrease in cross section toward small scattering angles ($\theta_L < 6°$). This behavior is well described by a single scattering model which includes the effects of Pauli blocking. Continuum analyzing power data are found to be very close to the values for free p-p and n-p scattering. However, spin-flip probabilities in ^{208}Pb ($E_p = 400$ MeV) and ^{90}Zr ($E_p = 500$ MeV) are significantly smaller than the free nucleon values.

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At small momentum transfers ($q < 3$ fm^{-1}) inelastic scattering with energy loss of 5 to 50 MeV leads to the excitation of broad giant resonances (GR) and a nearly featureless continuum, on which the GR's lie. Since, for hadron scattering, the continuum cross section is typically 5 to 10 times that contained in GR's, it is obviously of great interest to try to understand its excitation if only to understand better the characteristics of GR's. The nature of the continuum itself is also of interest, however. From a reaction theory viewpoint, it is important to know what mechanisms are involved in its excitation. Additionally, there may be nuclear structure information obtainable in the continuum.

In this Letter we address both points. We first show that the cross section for the low-excitation-energy continuum excited by 800-MeV protons may be understood in terms of a single-collision model based on Glauber theory.[1] A significant feature of the calculation, which is also seen in the data, is a decrease in the continuum cross section at small angles due to Pauli blocking. Then, looking at continuum analyzing powers and spin-flip probabilities, we present evidence that spin-dependent strength is greatly suppressed in the low-excitation-energy region of the nuclear continuum.

Beams of 400-, 500-, and 800-MeV polarized protons from the Clinton P. Anderson Meson Physics Facility were used to study the excitation energy region from 0 to 50 MeV in ^{90}Zr, ^{116}Sn, and ^{208}Pb. The inelastically scattered protons were momentum analyzed by the high-resolution spectrometer (HRS) and detected in an array of multiwire drift chambers which have been described previously.[2] The spin-flip probability measurements were obtained using the newly developed HRS focal-plane polarimeter.[3] This device consists of a carbon scattering target behind the normal focal-plane chambers plus two additional x-y planes of larger multiwire chambers behind the carbon target. Complete reconstruction of the trajectory is accomplished for all protons scattered in the polarimeter target. The scattering efficiency of the polarimeter is 7.5% at 400 MeV and the average analyzing power is near 0.35.

A typical GR-plus-continuum spectrum for 800-MeV protons on ^{116}Sn is shown in Fig. 1 together with theoretical curves discussed below. One sees the giant quadrupole-monopole resonance doublet near $E_x = 14$ MeV and the high-energy octupole resonance near $E_x = 23$ MeV. We have chosen the region near $E_x = 30$ MeV, which appears free of any obvious GR's, for evaluation of the angular distribution of the continuum shown in Fig. 2. A most interesting feature of the angular distribution is an obvious decrease in cross section at small scattering angles. This is, to our knowledge, the first evidence of such behavior. In GR studies with 100- to 200-MeV α particles (the bulk of all GR work) an exponential increase in continuum cross sections with decreasing scattering angle has always been observed.[4]

It is plausible to assume, for the scattering of intermediate-energy protons with small energy loss and small momentum transfer, that single collisions dominate. In this spirit, Bertsch and Scholten[5] have developed a model for continuum excitations based on Glauber theory.[1] The differential cross section is expressed as

$$d^2\sigma/d\Omega dE = (d\sigma/d\Omega)_{NN} N_{\rm eff} S(q,E),$$

where $(d\sigma/d\Omega)_{NN}$ is the differential cross section for free nucleon (N-N) scattering, and $S(q,E)$ is the nuclear response function. The effective number of target nucleons participating in the single-collision cross section, $N_{\rm eff}$, is determined as

$$N_{\rm eff} = \int d^2b\, \chi(b) e^{-\chi(b)}/\sigma_{NN}{}^T,$$

where

$$\chi(b) = \int_{-\infty}^{\infty} dz\, \rho \sigma_{NN}{}^T.$$

Taking $\sigma_{NN}{}^T = 40$ mb, we find $N_{\rm eff} = 7.6$ for scattering from ^{116}Sn at 800 MeV.

The response function is evaluated using the Fermi-gas (FG) model, and in the semi-infinite slab (SIS) approximation which treats the effects of Pauli blocking in the nuclear surface more realistically. The curve labeled FG in Fig. 1 (and Fig. 2) shows that the FG model is not able to account for the shape of the continuum spectrum. It does, however, yield the qualitative features of the angular distribution, in particular, the decrease in cross section at small angles. This decrease is due to the fact that the recoil nucleon does not have sufficient momentum to rise above the Fermi surface; it is thus Pauli blocked. The main defect of the FG model seems to be an overestimate of the Pauli blocking at small q. The SIS calculation, which will be described in detail elsewhere,[5] remedies this defect by giving the nucleus a surface region where the effects of Pauli blocking are partially suppressed. It is clear that a proper treatment of the surface is necessary for a realistic model of $S(q,E)$, since in ^{116}Sn, most of the contribution to $N_{\rm eff}$ comes from a region of the nucleus where the density is less than one quarter that of nuclear matter. The curves labeled SIS in Figs. 1 and 2 show that the spectral shape and angular distribution are now very well reproduced.

The evidence presented thus far strongly sug-

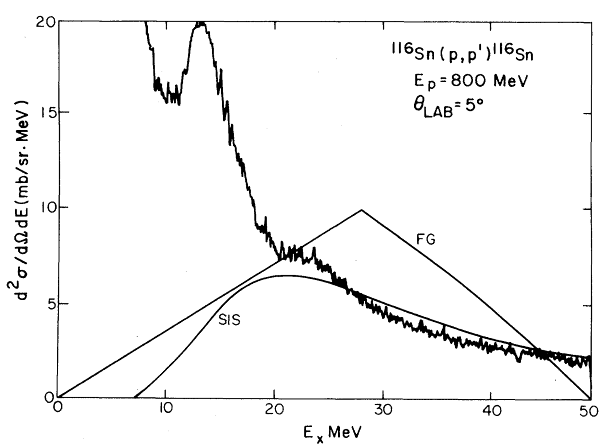

FIG. 1. Spectrum of ^{116}Sn compared to calculations using the Fermi-gas (FG) and semi-infinite slab (SIS) approximations.

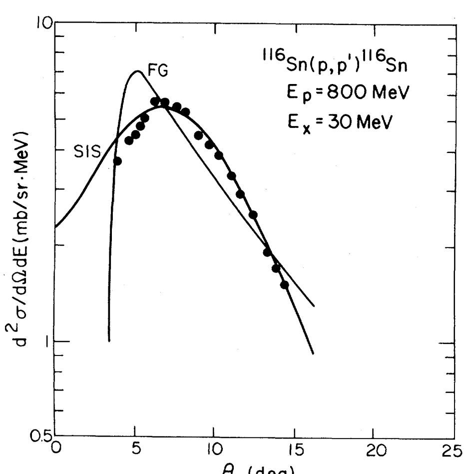

FIG. 2. Angular distribution of the continuum cross section at E_x = 30 MeV compared to calculations using the FG and SIS approximations.

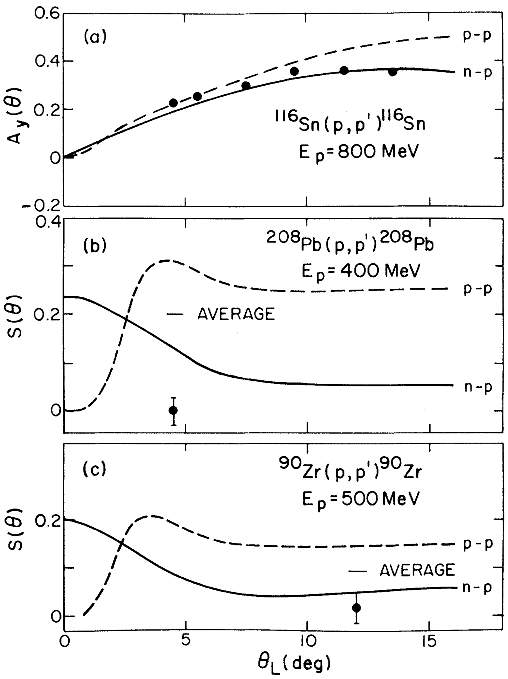

FIG. 3. (a) Analyzing power of the continuum at the energy of the quasielastic peak. (b) Spin-flip probability for the continuum from E_x = 7 to 22 MeV in ^{208}Pb. (c) Spin-flip probability for the continuum from E_x = 12 to 29 MeV in ^{90}Zr.

gests the dominance of single-step quasifree scattering. On this basis one would also expect the polarization observables for the continuum to be similar to the free N-N values. Figure 3(a) shows that this expectation is confirmed in the case of the analyzing power for the reaction ^{116}Sn(p, p')^{116}Sn at 800 MeV.[6] Very similar results are found for less extensive data on ^{90}Zr with 500-MeV protons and for ^{208}Pb at 400 MeV.

In sharp contrast to this simplicity, the spin-flip probabilities (SFP; S in figures and equations) for the continua in ^{208}Pb (7–22 MeV excitation energy at E_p =400 MeV) and ^{90}Zr (12–29 MeV excitation energy at E_p = 500 MeV) are consistent with zero, whereas the N- and Z-weighted values from the phase-shift solutions[6] are near 0.2 and 0.1, respectively.

We believe that the large difference between the free N-N and continuum SFP's is due, at least in part, to the difference between the scalar and vector (spin-dependent) response functions. It has been shown[7] that inelastic proton scattering with spin transfer (Δs =1) invariably leads to a large SFP (S > 0.5), whereas reactions in which Δs =0 dominates result in SFP's near zero. Thus the small SFP seen here implies a deficiency of Δs =1 over Δs =0 scattering with respect to the free N-N case. Nuclear collectivity associated with long-range fields is known to be mostly spin independent, with the result that the low-excitation-energy spectra of nuclei abound with scalar collective excitations (including GR's). Less is known about spin collectivity, but present evidence suggests that it is not nearly as strong as the spin-independent variety.[8,9] Qualitatively at least, the SFP data are in accord with this observation.

In summary, we have shown that the continuum in the region of giant resonances is quantitatively described by a quasifree scattering model which properly treats the effects of Pauli blocking and the surface-localized nature of the reaction. An anomalously small spin-flip probability in the excitation of the continuum with 400- and 500-MeV protons suggests a general dominance of spin-independent over spin-dependent excitation in the region E_x =7–29 MeV. As a final note, it would be extremely interesting to extend the spin-flip measurements to higher excitation energies in order to search for the "missing" spin-flip strength. In light of recent speculation concerning the role of the delta-isobar–hole configurations in the supression of the strength of spin-dependent giant resonances,[10] such experiments would appear to be extremely important.

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