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Interplay between multiple intranuclear scattering and pickup in proton-induced emission of ^{3}He into the continuum

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Abstract. The reaction ^{58}Ni(p,^{3}He)^{56}Co was investigated in the range from 80 to 120 MeV in order to determine whether the analyzing power of the direct pickup process decreases towards higher incident energies. Such quenching of the analyzing power is suggested by studies of inclusive proton-induced ^{3}He emission into the continuum, in which the direct pickup is preceded by multiple intranuclear N-N interactions. In pickup to discrete final states, it is now found that, as the incident energy is increased, the signature of large analyzing power moves to smaller scattering angles. This behaviour is consistent with the trend found in earlier continuum studies, thus the present study allows an unambiguous interpretation of the quenching effect.

1 Introduction

Recently proton-induced emission of ^{3}He into the continuum has been clearly linked to two-particle pickup as a final process in an intranuclear multistep chain [1–3]. A typical example [3] of how multiple intranuclear N–N collisions, which precede pickup of a neutron-proton pair to form an emitted ^{3}He particle, effect the analyzing power is shown in Fig. 1. At high emission energy, direct pickup dominates and the analyzing power angular distribution is prominent, with an associated relatively large value. As the multiple steps increase in importance, the non-zero excursion of the analyzing power becomes less prominent, until it no longer resembles the direct one-step pickup at the lowest emission energy in Fig. 1. This way in which the multiple scattering manifests itself appears to be independent of target mass over a large range [1–3], although detailed differences, which are correctly reproduced by the theory, are observed.

Another interesting feature of the continuum (p,^{3}He) reaction is that towards higher incident energy (say, up to 160 MeV), even at high emission energy where the single step reaction should dominate even more strongly, analyzing power becomes progressively smaller [1]. Nevertheless, the incident-energy quenching [1] of the analyzing power is still correctly reproduced by the multistep pickup model [1, 2]. As speculated in Ref. [1], the reason for this quenching of the analyzing power with incident energy is expected to be an inherent feature of two-nucleon pickup, and not a change in the reaction mechanism. However, at the

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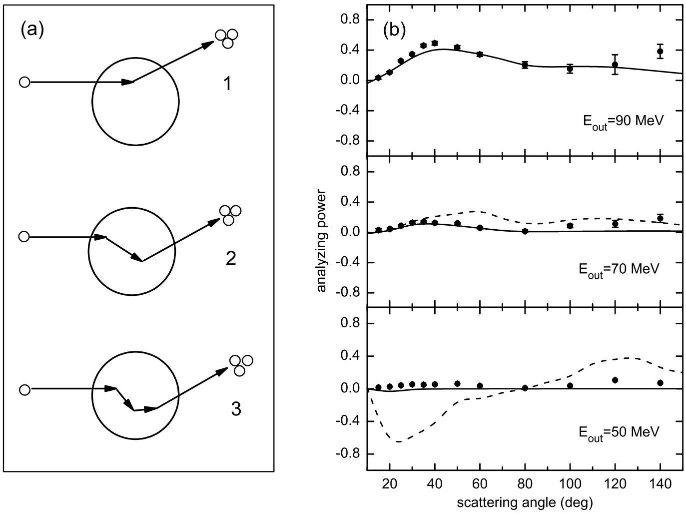

Figure 1. (a) Schematic representation of proton-induced emission of ^{3}He into the continuum of outgoing energies. The labels (1,2, or 3) indicate the number of intranuclear N-N interactions preceding and including the pickup process. (b) Analyzing power angular distributions for ^{93}Nb(p,^{3}He) at 100 MeV incident energy and various outgoing energies E_{out} from Cowley *et al.* [3]. Calculations for one step (dashed curves) and the sum of all steps (continuous curves) are shown.

incident energies explored, existing information on two-nucleon pickup reactions to discrete final states at appropriate projectile energies is inadequate to interpret the exact interplay between multistep and pickup processes in detail. For that reason we have performed a new experiment [4] on ^{58}Ni(p,^{3}He)^{56}Co at incident energies of 80, 100 and 120 MeV to address the deficiency. Some preliminary results, other than those presented here, have been reported at various scientific meetings [5–8]. In this paper we concentrate on the features of cross section and analyzing power angular distributions to discrete final states summed in the excitation-energy range of 0–6 MeV, and evaluate its importance for the understanding of the trend of inclusive proton-induced ^{3}He emission towards incident energies exceeding about 160 MeV or so.

2 Results and discussion

Results for cross section (a–c) and analyzing power (d–f) angular distributions for the reaction ^{58}Ni(p,^{3}He)^{56}Co are shown in Fig. 2 for incident energies of 80, 100 and 120 MeV. Values for all the states of the final nucleus prominently excited in the range 0–6 MeV were summed for cross sections and appropriately combined for analyzing power. Angular distributions for individual states were separately measured and compared [6–8] with distorted wave Born approximation (DWBA) predictions. The zero–range DWBA two-nucleon cluster transfer calculations were performed with distorted waves for the incident and exit channels derived from global optical model parameter sets. Full details of the theoretical calculations are provided in Refs. [4] and [8].

As may be seen in Fig. 2, a very good reproduction of the cross section and reasonable agreement with analyzing power to the summed distributions is provided by the theory.

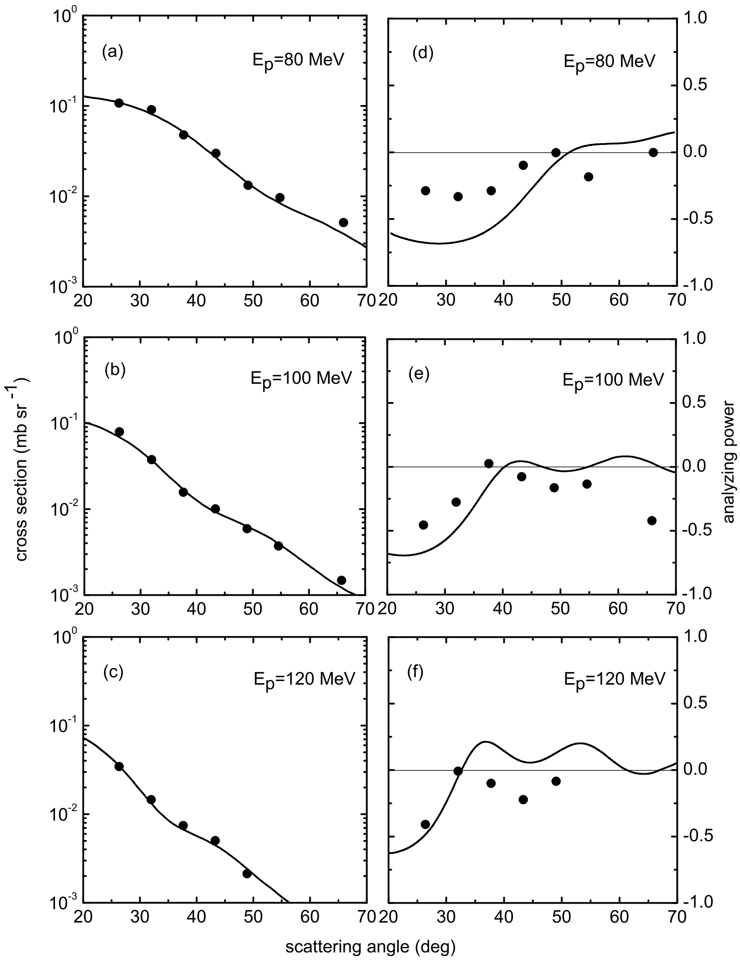

Figure 2. Summed cross section (a–c) and analyzing power (d–f) angular distributions for the reaction ^{58}Ni(p,^{3}He)^{56}Co to discrete final states in the excitation-energy range of 0–6 MeV. Projectile energies E_p are as indicated. Theoretical predictions, shown as curves, are based on distorted wave Born approximation calculations. Statistical error bars on the experimental data are smaller than the symbol size.

Fig. 2 reveals that, as the incident energy is increased, the non-zero part of the analyzing power (or stated more correctly – the values which differ appreciably from zero, as opposed to the small analyzing power values at larger angles) moves progressively to smaller scattering angles. Clearly, if this trend continues to even higher incident energy, the analyzing power is eventually limited by the constraint of a zero value at zero scattering angle.

It would have been desirable to extend the present investigation to even higher incident energy, but unfortunately a rapid decrease in the cross section with increasing incident energy causes experimental difficulty for accurate analyzing power measurements. Nevertheless, the present coverage already gives a very clear indication of the effect.

3 Summary and conclusion

It was found that a simple distorted wave Born approximation gives a good theoretical representation of the new experimental cross section and analyzing power angular distributions. The observed incident energy dependence of the (p,^{3}He) reaction to discrete final states explains why the characteristic signature of the multistep-pickup process in the continuum disappears as the incident energy increases beyond about 160 MeV.

The present conclusion is expected to hold in general for this type of reaction, because the quenching phenomenon observed in proton-induced inclusive ^{3}He emission appears to be applicable to a large range of target masses.

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