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A Note on Discrepancies Between (p,n) and $(p,n\tilde{p})$ Reactions on Nuclei near A = 208*

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ABSTRACT

The (p,n) and $(p,n\tilde{p})$ reactions on nuclei near A=208 were compared. No discrepancy in cross sections were observed but the width anomaly remains.

NUCLEAR REACTIONS: ^{208}Pb(p,n) and ^{208}Pb$(p,n\tilde{p})$, E_p=21-35 MeV measured σ.

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In a recent letter,[1] an explanation was offered to account for the discrepancies between $(p,n\tilde{p})$ and (p,n) reactions populating analogue states in the lead region. The discrepancies noted in that paper are: (1) the much larger cross section measured from $\tilde{p}$ decay than from the direct (p,n) reaction on ^{209}Bi to its isobaric analogue in ^{209}Po, and (2) the larger total widths of the analogue states observed in the $(p,n\tilde{p})$ reaction than in the direct (p,n) process on ^{208}Pb and ^{209}Bi. The second of these problems has been emphasized previously,[2] where an even larger discrepancy was observed for ^{207}Pb. However, the (p,n) and $(p,n\tilde{p})$ reactions on ^{206}Pb give similar total widths.

The letter by Grimes et al. attempts to account for these discrepancies in terms of the excitation of excited analogue states and their subsequent decay. We wish to suggest that problem (1) above does not remain and that the explanation offered for (2) does not apply. Thus, the discrepancy between the total widths for the same analogue state observed in (p,n) and in $(p,n\tilde{p})$ remains unexplained.

In a previous publication,[2] Crawley and Miller examined and ruled out the possibility that population of an excited analogue state in the ^{208}Pb$(p,n\tilde{p})$ reaction produces the width anomaly by running at bombarding energies above and below the threshold for the excitation of the first excited analogue state in ^{208}Bi. The large width was still observed in the decay below the threshold for excitation of an excited analogue state, thus ruling out this explanation. Grimes et al. also suggest that a more isotropic angular distribution near threshold could give additional broadening due to kinematic effects. However, in the analysis of previous data, the broadening from kinematic effects was taken into account explicitly in extracting the width of the analogue state.[2,3] In particular, three different shapes were assumed for the (p,n) angular distribution, including an isotropic distribution. Since the angular distribution for the ^{208}Pb(p,n) reaction at 25 MeV has recently become available,[4] a better estimate of the kinematic effects can now be made. Figure 1 shows the effect of the kinematics on the width of the $\tilde{p}$ peak shape for three different angular distributions. The following distributions were assumed: (a) the shape as measured at 25 MeV, (b) the shape calculated using a macroscopic distorted-wave calculation at 21.15 MeV using the same parameters which fit the data at 25 MeV, and (c) an isotropic angular distribution at 21.15 MeV. The figure shows that the maximum possible kinematic contribution is about 150 keV for case (a) at 90°, and decreases both at lower energies and for different angles of observation of the decay protons. The most realistic case (b) has a maximum width of only 92 keV. The conclusion is that kinematic effects cannot explain the anomalous width of about 320 keV observed for ^{208}Pb. The fact that there is no dramatic change in the line shape near threshold is also evidence against the kinematic explanation.

These measurements on ^{208}Pb(p,n$\tilde{p}$)[2] do not absolutely rule out the same explanation given by Grimes *et al*. for the case of

^{209}Bi(p,np) since there are two excited $T_>$ states in ^{209}Po, analogues of the 0.91-MeV ($7/2^-$) and 1.61-MeV ($13/2^+$) states in ^{209}Bi, which could in principle be excited by the (p,n) reaction at the bombarding energy of 21.15 MeV used in Ref. 2. However, two arguments make this explanation unlikely in the case of ^{209}Bi. First, no excited analogue states have been observed in (p,n) reactions on these heavy nuclei, and an upper limit of 1 to 2 mb has been placed on their total cross sections.[1] A limit of only 0.5 mb has been set for ^{208}Pb(p,n) to the first excited analogue state.[4] Microscopic calculations for the (p,n) reaction to the 0.91-MeV analogue state ($J^{\pi}=7/2^-$), using the code DWBA 70[5] and including exchange effects, suggest a total cross section of less than 0.1 mb. A similar result is expected for the 1.61-MeV ($13/2^+$) analogue state. Second order processes may enhance these cross sections, but, since these states are not collective, the inelastic scattering to them is small. Therefore second order processes involving inelastic excitation of the parent states[6] will probably not increase the cross section for the (p,n) reaction by more than a factor of 2 or 3. Such small total cross sections suggest that decays from these states are unlikely to contribute significantly to the total width observed.

In addition, all other aspects of the (p,n) and (p,n$\tilde{p}$) process for ^{208}Pb and ^{209}Bi appear very similar. The total widths measured by (p,n) and by the $\tilde{p}$ reaction show comparable discrepancies and similar behaviour with bombarding energy. The macroscopic Lane potential description of the charge-exchange reactions, which gives a good account of quasi-elastic scattering, predicts very similar cross sections and angular distributions for ^{208}Pb and ^{209}Bi. Any explanation which works for Bi should therefore also work for Pb.

The other problem posed by Grimes et al.[1] was that the total cross sections extracted from the ^{209}Bi(p,n$\tilde{p}$) reaction at 24.8 and 26.1 MeV proton-bombarding energies were 14.9 and 14.5 mb,[7] whereas the ^{209}Bi(p,n) cross section at 25 MeV was only 5.4 mb. Even if all the decay of the analogue state was by $\tilde{p}$ emission, the total (p,n$\tilde{p}$) cross section could not exceed the total (p,n) cross section for producing the state. This also suggested that extraneous particles must underlie the $\tilde{p}$ peak.

Recent measurements of the ^{208}Pb(p,n) total cross section give a value of 9.2 ± 1.0 mb at $E_p = 25.0$ MeV.[4] These measurements used a Lorentzian shape to extract the peak area, and this was observed to give a larger area than that obtained using a Gaussian shape. Both Lorentzian and Gaussian shapes give satisfactory fits to the peak shape (Fig. 2), but the Lorentzian shape has more theoretical justification.[8] A Lorentzian shape was also used to extract the peak areas in the $\tilde{p}$ experiment,[2,3] so that the method is also consistent for both (p,n) and (p,n$\tilde{p}$) experiments. The ^{208}Pb(p,n) cross section of 9.2 ± 1.0 mb is slightly higher than the value of 7.5 ± 0.9 mb reported by Schery[9] at a bombarding energy of 25.8 MeV. However, Schery's analysis used a Gaussian peak shape, so that a somewhat smaller value would be anticipated. The value of 9.2 ± 1.0 mb is substantially higher than the value of 5.4 mb reported by Grimes et al. for the ^{209}Bi(p,n) cross section.

In addition, the total cross section for ^{209}Bi(p,n$\tilde{p}$) derived from data reported by Crawley and Miller[2] is 11.3 ± 1.4 mb, and for ^{208}Pb(p,n$\tilde{p}$) the cross section extracted from the data at 25 MeV is 10.0 ± 1.4 mb. Both of these numbers are substantially smaller than the ^{209}Bi(p,n$\tilde{p}$) cross sections quoted by Grimes et al.[1,7]

We can certainly say that the cross section discrepancy for ^{208}Pb(p,n) and ^{208}Pb(p,n$\tilde{p}$) is not significant, since the measurements agree within their quoted accuracy, although this accuracy does not rule out a discrepancy of up to 30% instead of the factor of three[1] quoted for ^{209}Bi. For the ^{209}Bi case, it is probable that a similar situation exists. The measured $\tilde{p}$ cross section is close to the value for ^{208}Pb, and DWBA calculations for ^{208}Pb(p,n) and ^{209}Bi(p,n) suggest very similar total cross sections.

It is interesting to note that while no definite discrepancy in measured cross sections exists between the ^{208}Pb(p,n) and ^{208}Pb(p,n$\tilde{p}$), the $\tilde{p}$ cross section still appears to be slightly higher. The (p,n) cross section of 9.2 mb was obtained using a total width of 220 keV for the IAS; larger widths would give even larger cross sections. The 220-keV width was chosen to agree with earlier (p,p') resonance studies.[10] Even if the two cross sections were equal this would imply that the analogue state in ^{208}Bi decayed totally by proton emission. A predominance of proton emission is not observed in lighter nuclei,[11] or even for Au or Ta[1] where neutron emission predominates as soon as the neutron threshold is exceeded. The closed-shell structure around ^{208}Pb, which would imply large reduced widths for proton emission may explain this effect.

In summary, there does not appear to be any large discrepancy in cross section between the (p,n) and $(p,n\tilde{p})$ reactions for ^{208}Pb, and it is unlikely that a discrepancy exists for ^{209}Bi. The explanations suggested[1] for the total width discrepancy certainly do not account for the ^{208}Pb case, and also are unlikely to explain the discrepancy for ^{209}Bi.

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FIGURE CAPTIONS

Fig. 1--Kinematic effect of recoil motion on the proton energy spectrum for the $^{208}Pb(p,n\tilde{p})$ reaction, assuming that the recoil nucleus decays by monoenergetic proton emission (E_{CM}=11.452 MeV) after all interactions with the outgoing neutron have become negligible. The (p,n) Q-value used in the calculation is -18.828 MeV. Proton spectra at 45°, 90° and 135° in the laboratory are shown for three different (p,n) angular distributions: (a) measured at 25 MeV (Ref. 4); (b) distorted-wave calculation at 21.15 MeV; (c) isotropic at 21.15 MeV. The channel width is 20 keV.

Fig. 2--Neutron spectrum for $^{208}Pb(p,n)^{208}Bi$ in the region of the isobaric analogue of the target ground state. The fits shown are based on Lorentzian (solid) and Gaussian (dashed) intrinsic line shapes plus quadratic backgrounds. The area determined from the Lorentzian search is 50% larger than for the Gaussian.

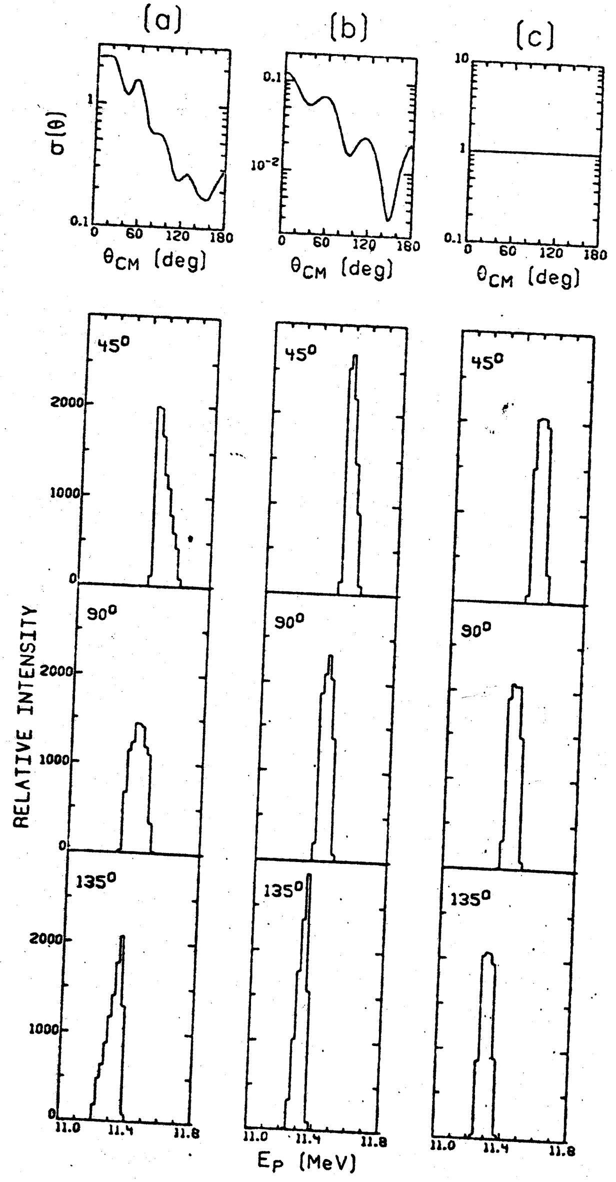

Figure 1

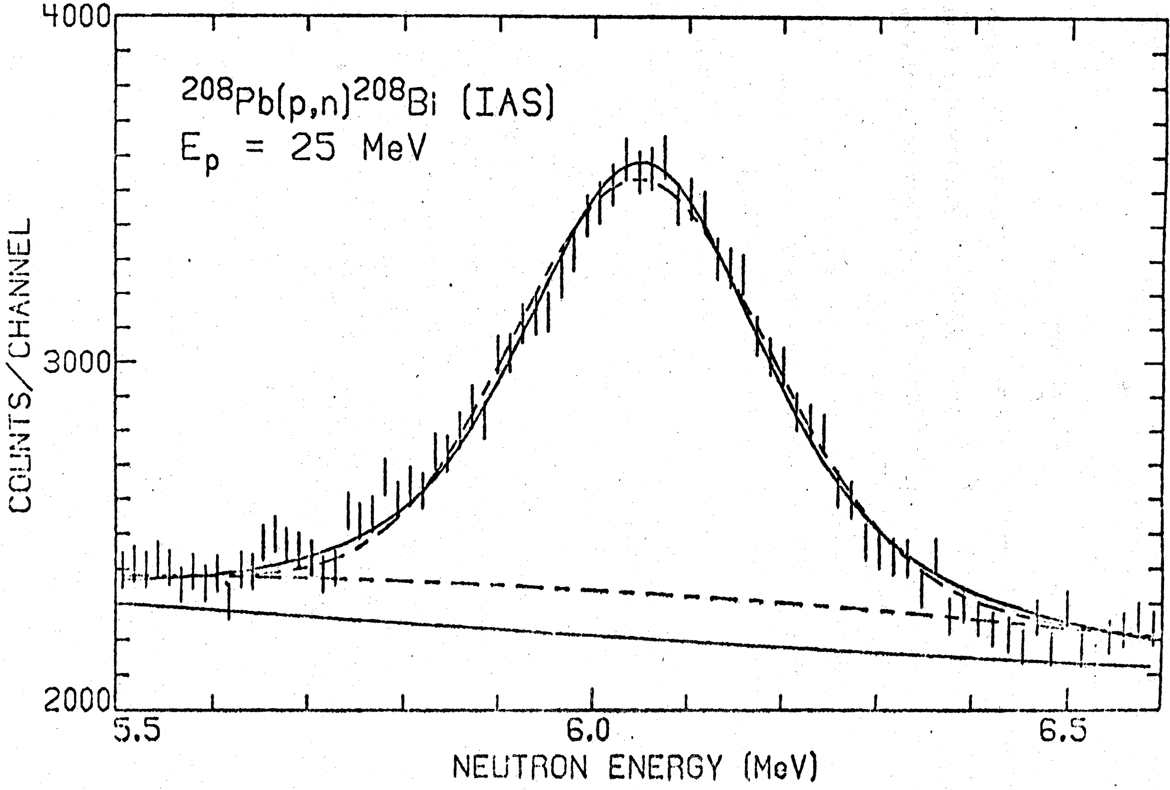
^{208}Pb(p,n)^{208}Bi (IAS)
E_p = 25 MeV
COUNTS/CHANNEL
2000
3000
4000
NEUTRON ENERGY (MeV)
5.5
6.0
6.5

Figure 2