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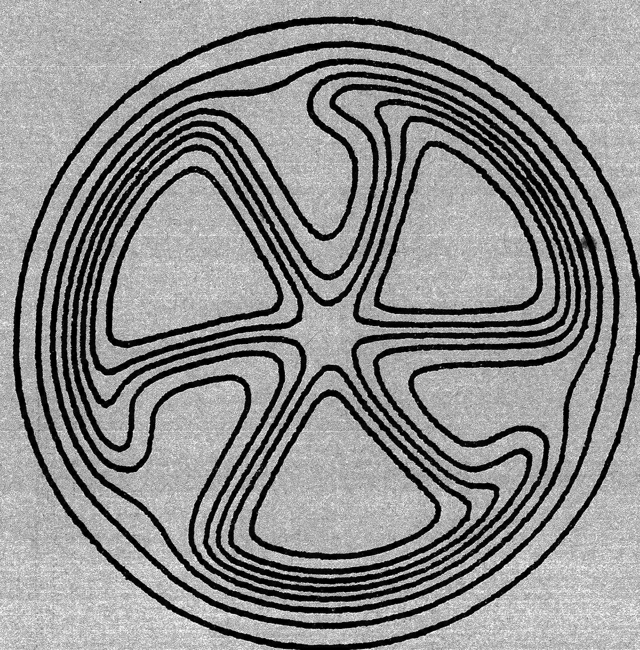

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Proton Decay of the Isobaric Analogs of the Ground States of ^{207}Pb and ^{208}Pb*

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ABSTRACT

Proton spectra have been observed in coincidence with neutrons produced in p+ $^{207,208}Pb$ reactions at 25 MeV. When gated by neutrons produced in exciting IAS, the usual $\tilde{p}$ groups representing proton decay of IAS to low-lying states of $^{206,207}Pb$ appear at 10-12 MeV. When gated by lower-energy neutrons, there are no $\tilde{p}$ groups at 10-12 MeV; rather, a single broad peak, presumably arising from evaporation, appears in this region of the proton spectrum. To this evaporation peak is attributed the anomalous situation in which the IAS formation cross section via (p,n) has appeared to be exceeded by its partial decay cross section via proton emission. Anomalously large IAS widths previously inferred from proton singles spectra are also attributed to the decay protons being superimposed upon this background evaporation peak. Our coincidence proton spectrum from $^{207}Pb(p,n\tilde{p})^{206}Pb$ reveals a narrower width, in agreement with ^{206}Pb+p resonance data and with $^{207}Pb(p,n)$ neutron spectra.

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Formation of isobaric analog states (IAS) in heavy nuclei has been extensively studied by proton elastic and inelastic resonance scattering[1-3] and by the (p,n) charge-exchange reaction.[4-6] Due to its unique nature, an IAS decays preferentially by proton emission to low-lying states of the final nucleus. Indirect observation of an IAS is therefore possible, and has been made, by detecting proton decay ($\tilde{p}$) of the analog state.[7-12]

The cross section for partial decay by $\tilde{p}$ emission from the IAS of ^{208}Pb [8,13] has been reported to be greater than the (p,n) cross section[6,14] for formation of the same IAS. A similar anomaly exists for the IAS of ^{209}Bi.[5,6,9] It would appear that processes other than population of the IAS are contributing to the $\tilde{p}$ yield. In addition to this discrepancy, the widths of the IAS of $^{207,208}Pb$ and ^{209}Bi as measured in (p,n$\tilde{p}$) experiments,[8,9,11] are considerably greater than the widths obtained in (p,n) experiments[4,6] or in ^{206}Pb+p [1] and ^{207}Pb+p [2,3] resonance experiments.

To explain these discrepancies it has been suggested[5] that proton decay of analogs of excited states may contribute to the $\tilde{p}$ yield. However, no direct evidence for the production of these excited analogs has been observed in (p,n) reactions on Pb and Bi, although they were looked for in many neutron spectra.[6,14] Instead, it has been surmised that a proton evaporation peak underlying the $\tilde{p}$ groups is responsible for excess $\tilde{p}$ cross sections and widths.[15] We present data which tend to support this proposition.

We have investigated the reaction mechanism of the $(p,n\tilde{p})$ process in ^{208}Pb and in ^{207}Pb by detecting the neutron and proton in coincidence. The proton bombarding energy was 25 MeV. Protons were detected at 90° with an E-veto telescope. A neutron time-of-flight (TOF) scintillation spectrometer[14] was used to detect the neutrons at 30° with respect to the beam. Pulse-shape discrimination was used to reject gamma rays. To achieve a reasonable coincidence counting rate, the neutron flight path was only 25 cm and the energy resolution 30%. The n-p coincidences were recorded on a magnetic tape and later replayed with appropriate gates to sort out the kinematic region of interest.

Figure 1 shows the neutron TOF spectrum for the ^{208}Pb target gated by protons between 10 and 12 MeV. The strong peak at 6 MeV corresponds to excitation of the target ground-state analog in ^{208}Bi. The gating protons include the $\tilde{p}$ decays of the IAS to the first three states of ^{207}Pb, the only states with non-negligible population.[8,11] The continuum background extending down to our threshold at 1.5 MeV are pre-compound and evaporation neutrons. The absence of a noticeable peak at 3.5 MeV speaks against the thesis that (p,n) excitation of the analog of the 2.61-MeV first-excited state of ^{208}Pb leads to appreciable numbers of 10-12 MeV $\tilde{p}$s.

Proton energy spectra, gated by various regions of neutron energy, are shown in Fig. 2. As the neutron energy

is lowered, conservation of energy allows the proton spectrum to extend to higher energy. For E_n=5-8 MeV (the IAS neutrons) we see $\tilde{p}$ groups at 11.5, perhaps 10.9, and 10.6 MeV corresponding to $p_{1/2}$, $f_{5/2}$, and $p_{3/2}$ decay of the IAS to the first three states, respectively, of ^{207}Pb. In coincidence with lower-energy neutrons there are always protons in the $\tilde{p}$ energy range, 10-12 MeV, but of course the 3-group structure of Fig. 2a and of Refs. 8 and 11 is not seen in Fig. 2b-e. Lack of this structure in Fig. 2c is another reflection of the low cross section for (p,n) excitation of the 2.61-MeV excited analog state.

All the spectra of Fig. 2b-e show yields at 10-12 MeV which are neither negligible compared to the yield in Fig. 2a nor constant with energy. In fact, the main feature of the structure in these spectra is a peak around 11 MeV. (Note that the 30% neutron energy resolution allows some IAS neutrons to be included in the neutron gate for Fig. 2b.) As a result of the superposition of these "background" peaks with the $\tilde{p}$ peaks, a cross section for proton decay of the IAS, if obtained without a neutron gate, i.e. from a proton singles spectrum, would very likely be an overestimate. We believe such over-estimates have been made and have resulted in the apparent cross-section anomalies previously cited. The shapes of the "background" spectra support the suggestion[15] that the $\tilde{p}$ peaks overlie what is mainly an evaporation spectrum cut off below approximately 10 MeV by the Coulomb barrier.

The other anomaly is in the IAS widths. By far, the greatest discrepancy occurs for the IAS of ^{207}Pb where both ^{206}Pb+p resonance measurements[1] and ^{207}Pb(p,n) spectra[4,6] give 0.2 MeV, whereas proton singles spectra from ^{207}Pb(p,np) show unresolved $\tilde{p}$ groups, implying a width of 0.5 MeV.[11] We have determined n-p coincidence spectra resulting from bombardment of ^{207}Pb with 25-MeV protons. The proton spectrum depends upon the neutron energy in a manner similar to that observed with the ^{208}Pb target.

Figure 3 shows a spectrum of ungated protons and a spectrum of protons in coincidence with IAS (ground-state) neutrons. The highest possible $\tilde{p}$ energies are 12.23 MeV and 11.42 MeV, followed by closely-spaced values beginning with 11.06 MeV. None of these groups is resolved in the singles spectrum, although spectra obtained with a detector of smaller solid angle and better resolution than in the present experiment had definite indications of the 12.23-MeV and 11.42-MeV groups.[11] In the coincidence spectrum of Fig. 3 the 11.42-MeV group is resolved from other structure and, considering the instrumental resolution of 0.3 MeV from target thickness and detector response, has an intrinsic width of 0.2 MeV, in agreement with the resonance and neutron-spectrum determinations. Decay to the ground state of ^{206}Pb is weaker compared to its underlying "background."

In conclusion, we find no evidence in the coincidence neutron spectrum for excited analog states. Rather, the coincidence proton spectra reveal under the $\tilde{p}$ groups a

peaked background, presumably due to evaporation. In proton singles spectra some of this background has, in the past, been erroneously attributed to $\tilde{p}$ decay, thus leading to both cross-section and width anomalies.

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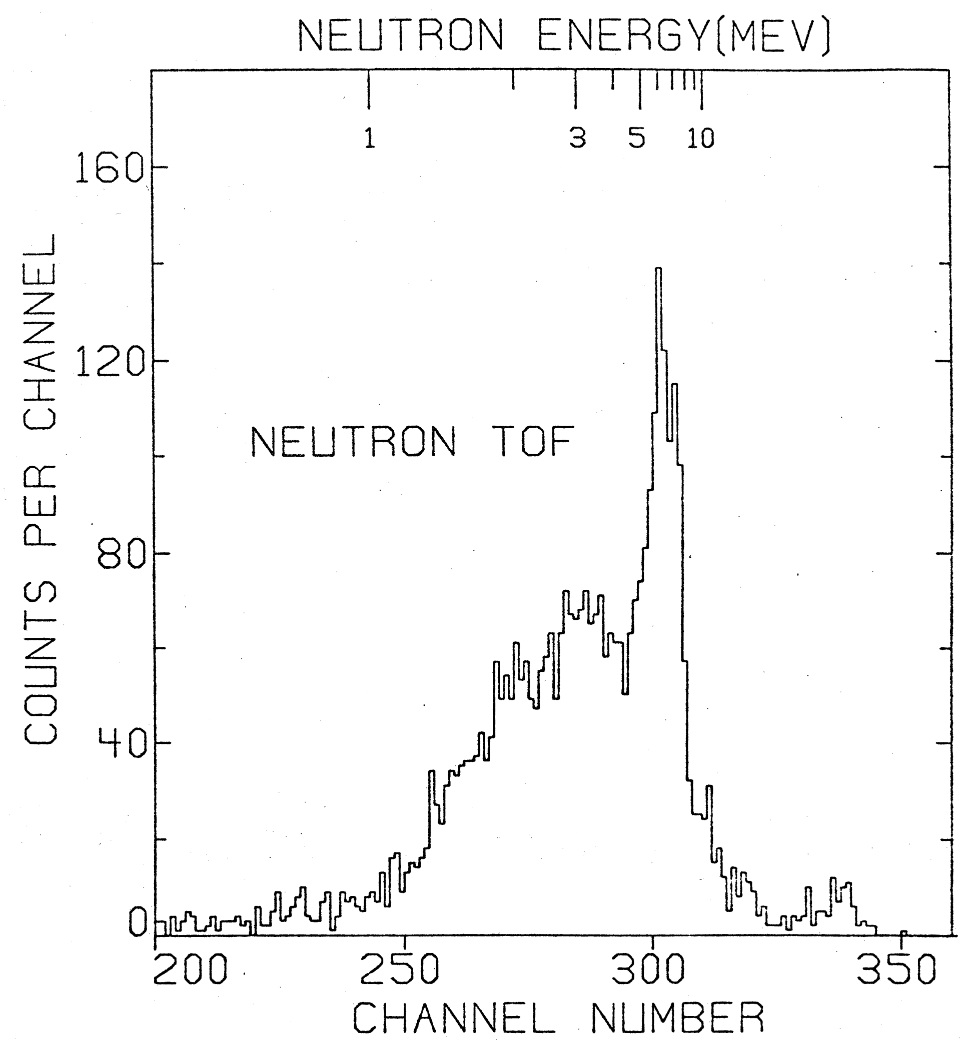
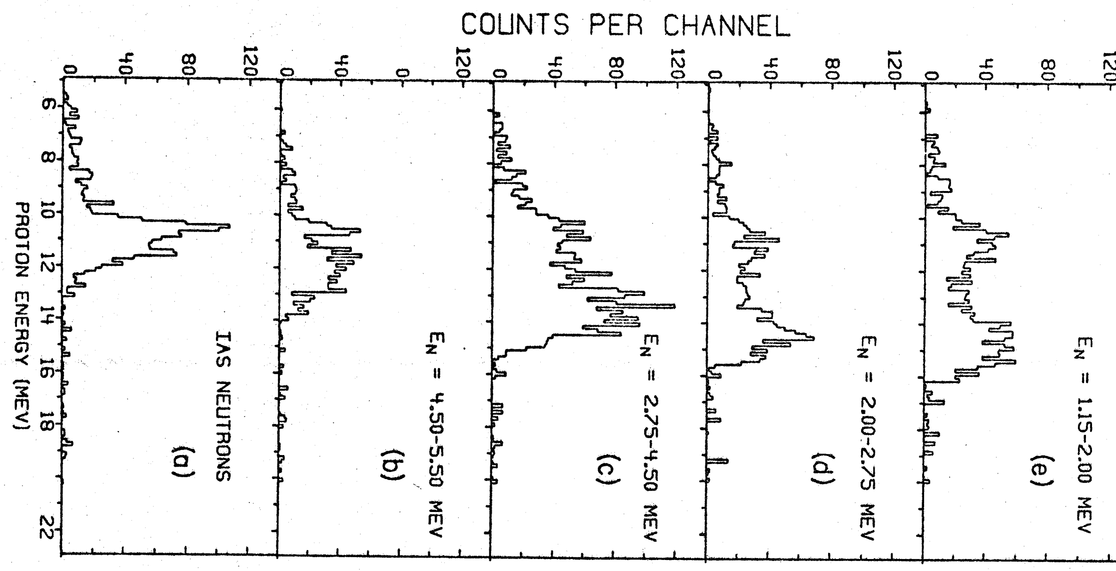
FIGURE CAPTIONS

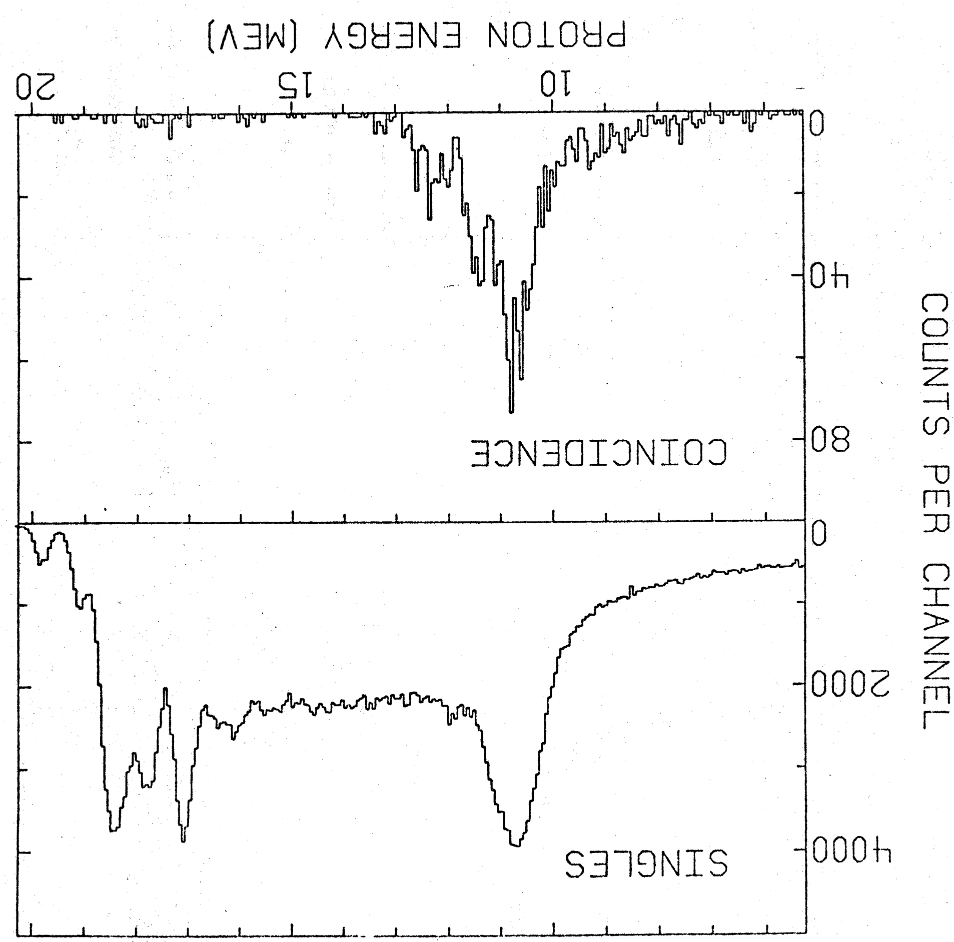
Fig. 1.--Neutron time-of-flight spectrum in coincidence with 10-12 MeV protons from $^{208}Pb(p,np)^{207}Pb$ at 25 MeV. The neutron threshold was set at 1.5 MeV. The neutron and proton reaction angles are 30^{o} and 90^{o}.

Fig. 2.--Proton spectra from $^{208}Pb(p,np)^{207}Pb$ in coincidence with neutrons (see Fig. 1) of various indicated energies.

Fig. 3.--Proton singles spectrum and coincidence spectrum from $^{207}Pb+p$ at 25 MeV. The neutron and proton reaction angles are 30^{o} and 90^{o}. The coincidence proton spectrum was gated by neutrons of energy around 6 MeV, which included those produced in the reaction $^{207}Pb(p,n)^{207}Bi(IAS)$.




COUNTS PER CHANNEL
PROTON ENERGY (MEV)
E_N = 1.15-2.00 MEV
(e)
E_N = 2.00-2.75 MEV
(d)
E_N = 2.75-4.50 MEV
(c)
E_N = 4.50-5.50 MEV
(b)
IAS NEUTRONS
(a)


COUNTS PER CHANNEL
PROTON ENERGY (MEV)
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