scattering or other dissipative processes do not seem to be of importance, i.e., that the N/Z mode is not overdamped like the mass-transfer mode. Also, the now available experimental evidence and theory[10] agree in that the characteristic times for N/Z relaxation depend only weakly on the size of target and projectile.

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Observation of the Proton-Pairing Vibration in ^{206}Pb

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The (^{3}He,n) reaction was studied at an incident beam energy of 33.3 MeV for targets of ^{204}Hg and ^{204,206,208}Pb. A 0^+ state at 4.1 ± 0.1 MeV in ^{206}Pb was excited with 70% of the cross section of the ^{206}Pb(^{3}He,n)^{208}Po(ground state) transition. This state lies at the predicted excitation energy of the proton-pairing vibration when particle-hole interactions are included.

Many nuclear phenomena can be described in terms of the coupling of three elementary modes of excitation: the single-particle, rotation-vibrational, and pairing modes. In heavier nuclei the first two modes have been well investigated experimentally by single-particle transfer and inelastic scattering. The pairing mode has also received considerable attention, with regard to the neutron degree of freedom, by the use of (t,p) and (p,t) reactions. The data around ^{208}Pb are in good agreement with a simple pairing vibrational model.[1] Indeed, all of the nuclear excitations investigated in the vicinity of ^{208}Pb appear to be well described by elementary modes. However, one important ingredient is missing. There exists no observation of excited proton-pairing 0^+ states or a systematic study of ground-state proton-pairing correlations for $Z=82$. Further, there has been recent interest in the possibility of α vibrations,[2] which are correlated four-particle, four-hole states analogous to the two-particle, two-hole proton- or neutron-pairing vibrations. The search for these α vibrations in the lead region[3] requires knowledge of the excitation energy of the previously unobserved proton-pairing vibration. The present Letter reports for the first time the observation of an excited proton-pairing vibrational 0^+ state in lead nuclei. Measurements of the appropriate differential cross sections and excitation energies permit a direct comparison to the harmonic pairing-vibration model.

Two-nucleon transfer reactions on targets with two nucleons less than a closed shell tend to populate an excited $J^\pi = 0^+$ state very strongly.[1] The pairing vibrational model[4,5] considers this state to be an elementary mode of excitation of the nucleus. In this model two particles coupled to spin zero outside a closed shell are treated as an addition quantum while two holes coupled to spin zero form a removal quantum. The excited state is viewed as an addition quantum plus a removal quantum and is called a pairing vibration. This model, in a purely harmonic approximation which neglects interactions between quanta, predicts that a two-nucleon transfer reaction leading to the pairing vibration will have the same Q value and cross section as the same reaction to the ground state on the closed-shell target. These predictions have been verified for (t,p) reactions near the neutron closed shells at $N=20$,[6] 28,[7] 50,[8,9] 82,[10] and 126.[11] When only the neutron shell is closed, the pairing vibration is often fragmented into a few states whose energy centroid and summed cross sections are in reasonable agreement with the harmonic pairing-vibration model.

The analogous proton-pairing vibrations have been studied less extensively because of experimental difficulties in the study of the $(^3\mathrm{He},n)$ reaction. Systematics similar to those for the (t,p) reaction have been observed in $(^3\mathrm{He},n)$ near $Z=20$[12] and $Z=28$.[13,14] Recently $(^3\mathrm{He},n)$ studies have been extended to the $Z=50$ shell closure[15] and have shown that, as in the neutron case, the pairing vibration is fragmented, although its summed strength agrees with the pairing-vibrational model.

The present work reports the observation of a strongly excited 0^+ state in the reaction $^{204}\mathrm{Hg}(^3\mathrm{He},n)^{206}\mathrm{Pb}$. Unfortunately, the doubly closed-shell nucleus $^{208}\mathrm{Pb}$ could not be investigated because the isotope $^{206}\mathrm{Hg}$ is not stable. However, the reaction $^{204}\mathrm{Hg}(^3\mathrm{He},n)^{206}\mathrm{Pb}$ leads to the same closed $Z=82$ shell, and a measurement of the pairing vibration here can indicate the position of such a state in $^{208}\mathrm{Pb}$ as will be shown below.

The data reported here were obtained with the University of Colorado rotating-beam neutron time-of-flight spectrometer[16] at an incident beam energy of 33.3 MeV. The experimental setup is described by Fielding *et al.*[17] although in the present work a small magnet was placed in the scattering chamber to deflect the $^3\mathrm{He}$ beam after it passes through the target to allow observation of neutrons at small angles. The isotopically enriched mercury targets were in the form of HgO deposited on isotopically enriched $^{24}\mathrm{Mg}$ backing to avoid interference from the reaction $^{13}\mathrm{C}(^3\mathrm{He},n)^{15}\mathrm{O}$ which occurred when carbon backings were used.[18]

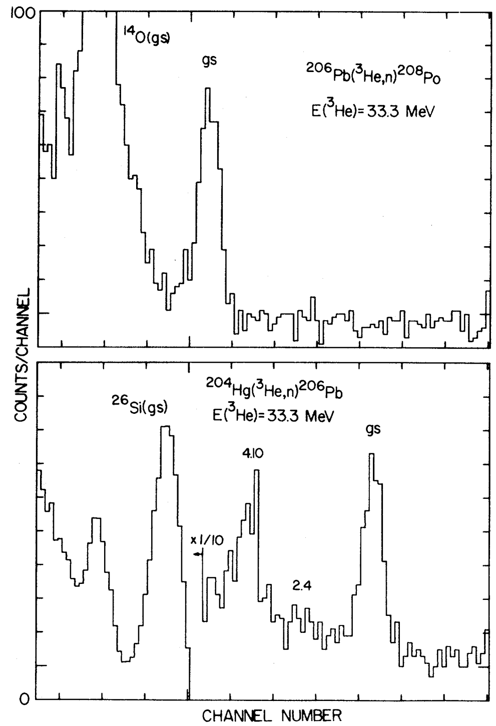

FIG. 1. Neutron time-of-flight spectra obtained at 4° for $^{206}\mathrm{Pb}$ and $^{204}\mathrm{Hg}$ targets. Increasing time is toward the left so that neutron energies increase toward the right. Time per channel is approximately 0.2 ns. Resolution is dominated by target thickness and corresponds to an energy resolution of about 500 keV.

Neutron time-of-flight spectra are shown in Fig. 1 for $^{204}\mathrm{Hg}$ and $^{206}\mathrm{Pb}$ targets. Figure 2 shows angular distributions for the ground states and the strongly excited state in $^{206}\mathrm{Pb}$ along with distorted-wave Born-approximation (DWBA) calculations using $^3\mathrm{He}$ parameters from set A of Erb and Gray[19] and neutron parameters from Becchetti and Greenlees[20] using the code DWUCK4.[21] The two-proton form factor was obtained by the method of Bayman and Kallio[22] assuming that the single-proton binding energy was one-half of the two-proton separation energy, taking into account the excitation energy of the residual nucleus. The height and position of the second maximum in the $L=0$ DWBA predictions shown in Fig. 2 are strongly affected by the choice of the neutron optical potential. However, all parameter sets tried agree in the shape of the strong forward maximum which is a unique feature of $L=0$ transitions.

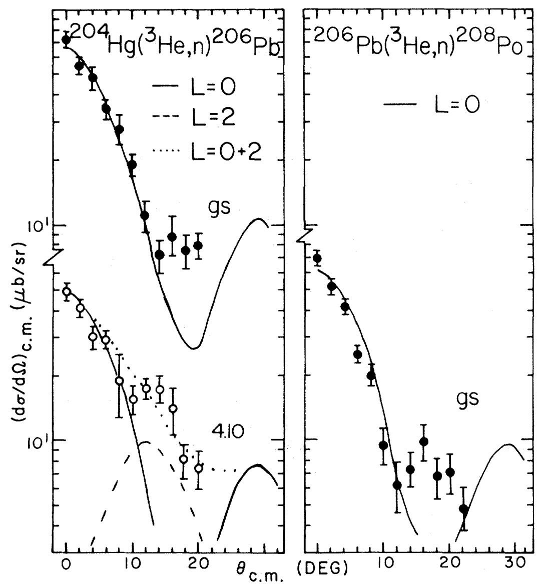

FIG. 2. Angular distributions for the ground state and the strong excited state seen with a ^{204}Hg target. Also shown is the ground-state transition seen with the ^{206}Pb target. The solid curves result from DWBA calculations described in the text. The small amount of $L = 2$ transfer shown for the 4.1-MeV state merely illustrates that unresolved higher-J states would not appreciably affect the assigned $L = 0$ strength.

The cross sections given in Fig. 2 are based on a monitor counter which was fixed at 40° in the scattering chamber. It was assumed that the ^{3}He elastic scattering from Pb, Hg, and Pt at 40° scales as predicted by the ^{3}He optical model of Ref. 19. Several other ^{3}He parameter sets gave the same results. A ^{196}Pt target, whose thickness was determined to be 4.2 mg/cm^{2} by weighing and by α-paritcle energy-loss techniques, was used to normalize the ^{204}Hg and ^{206}Pb data with the above assumption. The ^{206}Pb target thickness was independently measured by α energy loss and found to agree with the monitor counter determination. The Hg and Pb cross sections are estimated to have an absolute uncertainty of 15%. As seen in Fig. 2 the cross section for formation of the ^{206}Pb pairing vibration is ~70% of the ^{208}Po ground state (g.s.). This is a deviation of 30% from the prediction of the pairing-vibration model. An additional peak at 2.4 MeV is weakly populated by a mixture of $L = 0$ and $L = 2$ transfer. The $L = 0$ member of this doublet contains about 12% of the ^{208}Po(g.s.) strength.

Additional measurements were made for ^{204}Pb and ^{208}Pb targets and the cross sections to the ^{206,210}Po ground states were equal to that of the ^{208}Po ground state, within the 15% experimental error, indicating that neutron holes have little effect on the proton transfer cross section.

The excitation energy of the strongly excited state seen in the reaction ^{204}Hg(^{3}He, n)^{206}Pb is 4.1 ± 0.1 MeV and this excitation energy is taken as the location of the proton-pairing vibration in spite of the fact that this state contains only 70% of the expected strength. If the 2.4-MeV state is assumed to be a fragment of the pairing vibration, then 82% of the strength is located and a centroid energy of 3.85 MeV is obtained. However, if any additional strength lies at higher excitation it would tend to move the centroid to higher excitation. Such strength would be missed in the present measurements because of neutrons from the ^{24}Mg backing. A prediction of this centroid may be made by taking the difference of the ^{208}Po and ^{206}Pb ground-state two-proton separation energies and then correcting for particle-hole interactions.[23] The difference in the two-proton separation energies is 5.40 MeV. The particle-hole correction is four times the particle-hole interaction[23] of 324 keV and is principally due to the Coulomb contribution. This correction has been verified previously for the $Z = 50$ shell closure.[24] Such corrections are usually ignored in the neutron case because of the absence of the dominant Coulomb contributions. With use of the above procedure, an excitation energy of 4.1 MeV is predicted for the proton-pairing vibration in ^{206}Pb.

This agreement between predicted excitation energy and observed energy indicates that a prediction of the proton-pairing vibration of ^{208}Pb may be made. Using a similar procedure a value of 5.3 MeV is suggested for ^{208}Pb. This is in excellent agreement with the excitation energy of a weak 0^{+} state seen at 5.236 MeV in the reaction ^{210}Pb(p, t)^{208}Pb.[11] This state has been interpreted by Blomqvist[23] as the proton-pairing vibration, although experimental verification of this interpretation has been lacking heretofore. The present experimental results indicate that, when corrected for the particle-hole interaction, the harmonic pairing-vibration model for ^{208}Pb correctly describes the excited proton-pairing state.

The authors wish to thank Mr. Greg Smith for assistance in data acquisition. This work was supported in part by the U. S. Energy Research and Development Administration and the National Science Foundation.

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Island of High-Spin Isomers near $N = 82$

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(Received 11 July 1977)

Experiments aimed at testing for the existence of yrast traps are reported. A search for delayed γ radiation of lifetimes longer than ~ 10 ns and of high multiplicity has been performed by producing more than 100 compound nuclei between Ba and Pb in bombardments with ^{40}Ar, ^{50}Ti, and ^{65}Cu projectiles. An island of high-spin isomers is found to exist in the region $64 \lesssim Z \lesssim 71$ and $N \lesssim 82$.

Interest in the structure of nuclei at very high angular momentum has been stimulated by the growing availability of heavy-ion beams. Bohr and Mottelson[1] proposed some time ago that one manifestation of special structure effects in nuclei with high spin could be the occurrence of yrast traps. At high angular momenta, some nuclei may become oblate and are expected to carry angular momentum most efficiently not by collective rotation, but rather by successive alignment of particle spins along the symmetry axis. The yrast states will, on the average, have a rotationallike dependence of energy on spin with a mean effective moment of inertia equal to that of a rigid body rotating about the oblate symmetry axis. However, deviations from the mean, enhanced by shell effects, may cause such large irregularities in the yrast sequence of energies that yrast isomers can occur. In addition, since transition probabilities between such states are determined by single-particle matrix elements, isomers may occur by virtue of selection rules for single-particle transitions.

A number of groups have performed detailed