reproduced the experimental angular distributions. The pattern of small oscillations superimposed on large oscillations suggests passage of the projectile through the nuclear surface region without strong absorption. The fine oscillations are produced by interference between surface-penetrating orbits and grazing orbits on the far side of the nucleus. There is no experimental evidence yet for the existence of the small oscillations, but the narrow forward peak appears to be authentic. Although inclusion of recoil could alter these fits, it would not be expected to change the prime conclusions to be drawn from the study on two-neutron transfer[1] and the present paper on single-proton transfer: Absorption of heavy ions in the nuclear interior appears to be weaker than has been previously recognized. In addition this work demonstrates that weak absorption leads to dependence of angular distributions on form factor shapes, i.e., on transferred L.

Added note.—Recent DWBA calculations which include recoil effects (A. J. Baltz and S. Kahana, to be published) yield angular distributions for the "normal" L transfers ($L=j+\frac{1}{2}$) largely unchanged in shape and slightly stronger than those shown above. Non-normal transfers possible for our cases possess $L=j-\frac{1}{2}$ and therefore contribute weakly (~few percent in magnitude) to the cross sections. Hence DWBA predictions for this reaction obtained in a no-recoil approximation are changed little when recoil effects are included.

In an ongoing experiment, additional data for the ^{49}Sc ground state were taken with a counter telescope in the conventional manner and have been added to Fig. 3. These data give additional evidence of the forward peak for $L=4$.

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Short-Lived α Emitters of Thorium: New Isotopes $^{218-220}$Th

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The α-decay energies and half-lives of three new thorium isotopes, $^{218-220}$Th, have been measured by a simple recoil technique. The observed α-decay widths are in qualitative agreement with Mang's shell-model theory.

The sudden decrease of α-decay reduced widths in translead elements with neutron numbers $N<128$ has been known for more than a decade.[1] Initially interpreted as an indication of a sudden change in the nuclear radii, the data have since found a more natural explanation by considering the shell structure of parent and daughter nuclei.[2] For daughter nuclei near the neutron shell closure at $N=126$, the extra binding implies correspondingly short half-lives in the submillisecond region. The majority of nuclei near $N=128$ have so far been studied by the helium-jet transport technique[3-6] which is useful for parent half-lives in excess of 1 msec. The short-lived nuclei of interest have been observed as members of a decay chain starting from sufficiently long-lived parent nuclei. More recently, a measurement has been reported[7] making use of the pulsed beam from a heavy-ion cyclotron. The present Letter presents measurements of α-decay energies and half-lives of $^{217-220}$Th, so far the most proton-rich nuclei near $N=128$. The experiment was performed with a variable-rate, fast beam-pulsing system on the MP tandem accelerator and used a sensitive recoil technique which should allow studies of more neutron-deficient nuclei in this mass region.

The thorium isotopes were produced by the (^{16}O, $3n$) and (^{16}O, $4n$) reactions on enriched targets of $^{204,206-208}Pb$ by using pulsed ^{16}O beams from the upgraded Chalk River MP tandem accelerator. The beam-pulsing system,[8] located between the injector and the low-energy end of the accelerator, was used in two modes. For the study of submicrosecond isotopes an electrostatic deflector and a two-gap buncher provided 5-nsec-wide beam pulses on target, with a pulse spacing of 400 nsec. Longer-lived isotopes were observed by using only the deflector to produce pulse widths in excess of 0.5 μsec with adjustable repetition rate. Reaction products recoiling out of the target were collimated to $\pm 5°$ and stopped in a 0.4-mg/cm^2-thick catcher foil of carbon selected for low in-beam background. The arrangement is shown schematically in Fig. 1(a). α particles from the catcher foil were observed between beam bursts in a 100-μm-thick annular surface-barrier detector shielded from charged particles coming directly from the target. A transverse magnetic field of ~1 kG was applied between catcher foil and detector to reduce background from low-energy electrons. With the present arrangement most of the recoils from the (^{16}O, xn) reactions are collected, while background from spontaneous fission and α activities from heavy-ion transfer reactions are strongly suppressed. This feature is of importance because the fission cross section alone[9] is about 2 orders of magnitude larger than the cross sections of interest.

α activities were assigned on the basis of excitation functions and parent-daughter relationships. As an example a delayed α-particle spectrum following bombardment of a 0.6-mg/cm^2-thick ^{206}Pb target with 91-MeV ^{16}O is shown in Fig. 1(c). The α groups from the new isotopes ^{218}Th and ^{219}Th have intensities roughly equal to groups from their known daughters ^{214}Ra and ^{215}Ra. The assignments are further confirmed by the yield curves [Fig. 1(b)] whose maxima occur at bombarding energies expected for (^{16}O, $3n$) and (^{16}O, $4n$) reactions. Figure 2(a) shows a time spectrum for the 9.34-MeV α group from ^{219}Th corresponding to a half-life $T_{1/2} = 1.05 \pm 0.03$ μsec for this isotope.

The results on α-decay energies, Q_α values (including recoil and screening corrections) and half-lives of $^{217-218}Th$ are summarized in Table I. The data are from the present work with the exception of the alpha-decay energy of ^{217}Th which was given previously.[5] The α energies were determined using thin sources of ^{241}Am and ^{212}Bi as energy standards and after correcting for energy loss in the catcher foil. The Q_α values of the new isotopes agree well with the mass predictions of Wapstra and Gove.[10] The α energies of groups from Ra and Rn daughters were in excellent agreement with previous work except for ^{216}Ra, where our $E_\alpha = 9.34 \pm 0.02$ MeV is slightly larger than previously quoted values.[7,11]

From the experimental decay widths Γ_α, reduced widths γ_L^2 were calculated using the relation $\gamma_L^2 = \Gamma_\alpha / 2P_L$, where P_L is the penetrability of an α particle with angular momentum L facing a Coulomb potential at an assumed radius R

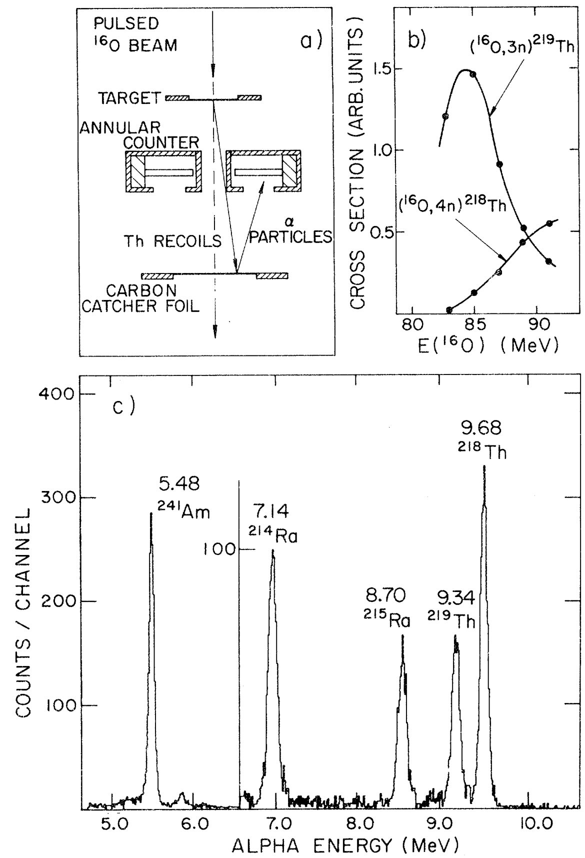

FIG. 1. (a) Experimental arrangement. (b) Excitation functions for the production of $^{218,219}Th$ using the reactions $^{206}Pb(^{16}O, 3n)$ and $^{206}Pb(^{16}O, 4n)$. The units are approximately millibarns. (c) Delayed α-particle spectrum from bombardment of a ^{206}Pb target with 91-MeV ^{16}O. The energy resolution is about 100 keV, and the α energies given are corrected for energy loss.

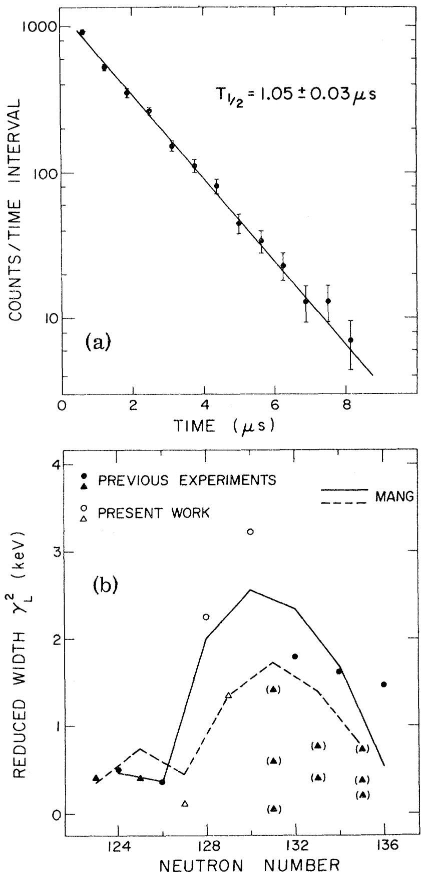

FIG. 2. (a) Decay curve of the 9.34-MeV α group from ^{219}Th observed using a time-calibrated time-to-amplitude converter. (b) Reduced α-decay widths γ_L^2 for known α emitters of thorium. Theoretical widths calculated from Ref. 2 are given separately for even (solid lines) and odd (dashed lines) nuclei. Experimental values for even (open circles) and odd (open triangles) nuclei were extracted as explained in the text. Data in parenthesis are uncertain because of unknown spins and the existence of several decay branches.

$= 1.57A^{1/3}$ fm. The reduced widths γ_L^2 are compared in Table I with calculations based on the shell-model theory of Mang.[2] Unique configurations of $1h_{9/2}^{N_1}(\pi)2g_{9/2}^{N_2}(\nu)$ and spins of 0^+ or $\frac{9}{2}^+$ were assumed for parent and daughter nuclei with $N \geq 126$. For isotopes with $N < 126$ the $3p_{1/2}$ and $2f_{5/2}$ neutron orbitals were assumed to contribute to the α decay. The comparison is extended in Fig. 2(b) to all known α emitters of thorium. Some of the experimental values above ^{221}Th are shown in brackets because several branches with similar α-decay energies exist, and spin values are unknown for both parent and daughter nuclei. Furthermore, the assumption of pure configurations should be less reliable for these nuclei. The theory reproduces well the sharp drop of γ_L^2 below $N = 128$ and the pronounced odd-even effect above $N = 128$. The agreement near $N = 128$ is impressive considering the simplifying assumptions of the theory, and lends support to the spin values and configurations assumed for the ground states of these isotopes.

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TABLE I. α decay of $^{217-220}$Th.

Isotope	α energy (MeV)	Q_α(expt) (MeV)	Q_α(predicted)[a] (MeV)	$\tau_{1/2}$(expt)	L value assumed	γ_L^2(expt)[b] (keV)	γ_L^2(theory)[c] (keV)
^{217}Th	9.25 ± 0.02	9.46 ± 0.02	9.42	252 ± 7 μsec	5	0.098	0.44
^{218}Th	9.68 ± 0.02	9.90 ± 0.02	9.90	122 ± 8 nsec	0	2.24	2.00
^{219}Th	9.34 ± 0.02	9.55 ± 0.02	9.40	1.05 ± 0.03 μsec	0	1.44	(1.44)
^{220}Th	8.79 ± 0.02	8.99 ± 0.02	9.00	9.7 ± 0.6 μsec	0	3.23	2.56

[a]Ref. 10.

[b]Derived from the experimental half-lives by assuming branching ratios of 100%. The quoted γ_L^2 are about a factor of 70 smaller than the reduced widths δ_L^2 tabulated by Rasmussen (Ref. 1).

[c]Relative reduced widths calculated from Ref. 2 using pure shell-model configurations for parent and daughter nuclei. The calculated reduced widths were normalized to the experimental reduced width for ^{219}Th.

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Null Search for Bursts of Gravitational Radiation

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A calibrated detector of kilohertz-band gravitational radiation has been built which has sufficiently improved sensitivity over Weber's apparatus to allow comparison with his two-detector coincidence results. No events were observed by us at 710 Hz during a recent three-month period of observation. Weber's data at 1661 and 1030 Hz would imply that we should have seen more than 400 events. During these observations, our sensitivity to gravitational bursts was many times that of Weber during 1969–1970. Absolute limiting flux values are given.

Large bursts of kilohertz-band gravitational radiation have been reported by Weber.[1-3] The most significant features of Weber's observations and analysis are his claims of (1) excess coincidences (above chance due to noise) in a two-detector system and (2) a sidereal correlation of these coincidence events. Estimates[4,5] of Weber's detection sensitivity to gravitational radiation imply mass loss rates of $(10^4-10^5)m_{\odot}$/yr for our galactic nucleus, if the source is there. Questions regarding Weber's sensitivity claims have been raised by others.[5-7] We examine here only the implications of claim (1). Sufficiently large bursts should produce unmistakable output on a single, large detector of adequate sensitivity. A two-detector experiment is not necessary if local interference is small. Although Weber's detectors are not calibrated directly, existing data on his system provide some yardstick for comparison of our independent results. In this Letter we examine Weber's limiting noise using published data,[3,8] report our observations, and compare our flux limit with our estimate of Weber's minimum detectable flux.

It is necessary to perform the classic Weber two-detector coincidence experiment in order to verify the claimed flux of gravitational radiation (GR); occasional signals in a one-detector system might come from some local source of interference. However, given this claimed observation of GR above a certain flux level, a more sensitive single-detector null result is sufficient to disprove the claim.

For the mechanically resonant aluminum bar (one-dimensional oscillator) detectors discussed here, the energy of oscillation varies slowly, except during shock excitation. Per mode, the resonant bar has an rms thermal potential or kinetic energy (Brownian motion) of $\frac{1}{2}kT$. A sudden increase in this energy due to a burst of gravitational radiation can be distinguished from Brownian motion. For two detectors in coincidence, this ultimate energy resolution depends on the type of signal processing and extra noise present. In nuclear counting, the signal-to-noise ratio (S/N) is greatly improved by using two detectors in coincidence because the "noise" pulses are brief compared to the time between pulses. However the detection systems discussed here are limited (see below) by wide-band white noise, and a two-detector coincidence system gains no more than a factor of 2 in S/N over one detector. More exactly, a two-detector coincidence system is not more than twice as sensitive than one detector if the signal is less than the limiting Brownian-motion and preamplifier noises. However, a two-detector system does offer immunity from occasional local interference. Finally, in a null-check experiment of this kind, we must be careful to address the questions of detector frequency, threshold sensitivity, and signal signature assumed in the data analysis.

In maximizing the sensitivity of a detector system to gravitational radiation, we must optimize several parameters.[9] The transducer has capacitance C_2. We define β as that fraction of the