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^7Li -Induced Reactions for Fast-Timing With $\text{LaBr}_3\text{:Ce}$ Detectors

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Abstract.

^7Li induced-reactions have been used with a ^{186}W target to populate nuclei around $A \sim 180 - 190$ at the National Institute of Physics and Nuclear Engineering in Bucharest, Romania. An array of high-purity germanium (HPGe) and cerium-doped lanthanum bromide ($\text{LaBr}_3\text{:Ce}$) detectors have been used to measure sub-nanosecond half-lives with fast-timing techniques. The yrast 2^+ state in ^{190}Os was measured to be $t_{1/2} = 375(20)$ ps, in excellent agreement with the literature value. The previously unreported half-life of the 564-keV state in ^{189}Ir has also been measured and a value of $t_{1/2} = 540(100)$ ps obtained.

Keywords: Fast timing, half-life measurements, ^7Li -Induced Reactions, $\text{LaBr}_3\text{:Ce}$ Detectors

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INTRODUCTION

^7Li is a weakly-bound stable nucleus, with a threshold of ~ 2.5 MeV for break-up into an α particle and a triton [1]. Thus, reactions using a ^7Li beam can take place involving only

the triton immediately following break up, often called incomplete fusion, populating nuclei inaccessible with complete fusion reactions. Of particular interest is the (${}^7\text{Li}, \alpha p$) reaction, in which two neutrons from the triton are transferred to the target nucleus. This gives the possibility of accessing nuclei on the neutron-rich side of stability using a stable beam and target combination at low energy.

Such reactions involving two-neutron transfer have recently begun to be exploited at the National Institute of Physics and Nuclear Engineering (IFIN-HH) in Bucharest, Romania to measure the half-lives of low-lying states using a mixed array of high-purity germanium (HPGe) and cerium-doped lanthanum bromide ($\text{LaBr}_3\text{:Ce}$) detectors [2]. $\text{LaBr}_3\text{:Ce}$ detectors boast excellent timing resolution (100–300 ps) and good energy-resolution ($\sim 2\text{--}3\%$ at 662 keV), allowing for measurement of nuclear lifetimes down to tens of picoseconds [2].

EXPERIMENT

A 16 mg/cm^2 enriched ${}^{186}\text{W}$ target with a 43 mg/cm^2 lead backing was bombarded with a ${}^7\text{Li}$ beam delivered at an energy of 31 MeV by the Tandem van de Graaff accelerator at IFIN-HH, Romania. This beam energy was chosen to be close to the Coulomb barrier of $\sim 29\text{ MeV}$ in order to suppress fusion-evaporation reaction channels. The experiment ran for ~ 218 hours, during which the average beam intensity was ~ 4 particle-nA. γ rays produced in the reaction were detected with an array of eight HPGe detectors and eleven $\text{LaBr}_3\text{:Ce}$ detectors. The detectors were calibrated in energy using ${}^{152}\text{Eu}$ and ${}^{60}\text{Co}$ sources and the energy dependence of the timing for the $\text{LaBr}_3\text{:Ce}$ detectors was calibrated with a ${}^{60}\text{Co}$ source using the method described in Ref. [2].

RESULTS

The strongest reaction channels populated in the present experiment were the ${}^{186}\text{W}({}^7\text{Li}, \alpha 2n){}^{187}\text{Re}$ and ${}^{186}\text{W}({}^7\text{Li}, 4n){}^{189}\text{Ir}$ reactions. ${}^{189}\text{Ir}$ is populated in (complete) fusion-evaporation and ${}^{187}\text{Re}$ is likely populated through a combination of complete and incomplete-fusion and transfer processes. The spectrum in Fig. 1(a) is the result of gating on the 114-keV γ ray in ${}^{189}\text{Ir}$ and shows other transitions in this nucleus.

Also populated in the reaction was ${}^{188}\text{W}$, created through the ${}^{186}\text{W}({}^7\text{Li}, \alpha p){}^{188}\text{W}$ incomplete-fusion / transfer reaction. This reaction channel is weakly populated and was estimated to be $\sim 0.5\%$ of the total γ - γ statistics collected in the experiment. Fig. 1(b) shows the result of gating on the 143-keV, $2^+ \rightarrow 0^+$ transition of ${}^{188}\text{W}$, showing other previously reported transitions in this nucleus [6]. The half-life of the yrast 2^+ state was measured and the results will be presented in a forthcoming publication [7].

In order to test the timing properties of the $\text{LaBr}_3\text{:Ce}$ detectors, the previously-reported [8] half-life of the yrast 2^+ state in ${}^{190}\text{Os}$ was measured. ${}^{190}\text{Os}$ was populated in the electron-capture decay of ${}^{190}\text{Ir}$ and was measured out-of-beam from the target activity after the experiment. The half-life was measured from the time difference between the 361-/371-keV doublet, both of which feed directly into the 2^+ state, and the 187-keV transition depopulating the 2^+ state [8]. As the density of peaks in the

FIGURE 1. HPGc γ ray spectra in coincidence with (a) the 114-keV transition and (b) the 143-keV transition detected in the HPGc detectors. The spectra show transitions in (a) ^{189}Ir [3, 4, 5] and (b) ^{188}W [6]. Peaks belonging to ^{189}Ir and ^{188}W are labeled by their energies in keV.

LaBr₃:Ce energy spectra was much lower in the decay spectra than those recorded in beam, it was not necessary to use a HPGc coincidence gate to isolate the transitions of interest in ^{190}Os . Thus the statistics available to measure the yrast 2^+ state in ^{190}Os were relatively large, allowing for a precision measurement.

Figure 2(a) shows the time difference spectrum between the 361-/371-keV doublet and the 187-keV transition in ^{190}Os . The spectrum was fitted with a convolution between the exponential decay of the state and a Gaussian prompt response of the detector array. The half-life and height of the exponential and the $\Delta T = 0$ centroid and full-width at half-maximum (FWHM) of the Gaussian were all allowed to vary freely in the fit. The half-life of the yrast 2^+ state in ^{190}Os was measured as $t_{1/2} = 375(20)$ ps in excellent agreement with the literature value of $t_{1/2} = 375(10)$ ps [8]. When fitting in-beam time-difference spectra in the present work, the centroid and FWHM of the prompt response were fixed to the values obtained in the fit to the yrast 2^+ state in ^{190}Os .

The half-life of the 564-keV state in ^{189}Ir [3] has been measured in-beam and a value of $t_{1/2} = 540(100)$ ps was obtained. A HPGc coincidence gate on the 187-keV, $7/2^+ \rightarrow 5/2^+$ transition was used to create clean LaBr₃:Ce spectra for ^{189}Ir and the half-life was measured from the time difference between the 178- and 263-keV transitions, directly feeding and depopulating the 564-keV state. Figure 2(b) shows the time difference spectrum for the 564-keV state in ^{189}Ir .

The 564-keV state has been assigned a $9/2^-$ spin-parity in Refs. [4, 5] based on a stretched $E1$ character for the depopulating 263-keV transition, feeding the $7/2^+$ state of the ground state band (GSB). The $9/2^-$ state is reasoned to have a single-particle structure based on the $h_{9/2}$ orbital [4, 5]. The 564-keV state is also depopulated by a 110-keV transition to the $9/2^+$ state of the GSB [5]. Assuming the 110-keV transition to have an $E1$ character, a branching ratio of 0.83(8) and thus a reduced transition probability of

FIGURE 2. (a) Time difference between the 361-/371-keV doublet and the 187-keV transition in ^{190}Os . The solid line is a fitted Gaussian-exponential convolution to the data and the dashed line represents the deconvoluted Gaussian prompt response of the array. The half-life of the yrast 2^+ state in ^{190}Os was measured to be $t_{1/2} = 375(20)$ ps. (b) Time difference between the 178-keV and the 263-keV transitions in ^{189}Ir , gated by the 187-keV transition of ^{189}Ir observed in the HPGe detectors. The half-life of the 564-keV, $9/2^-$ state in ^{189}Ir was measured to be $t_{1/2} = 540(100)$ ps.

$B(E1) = 3.7(8) \times 10^{-5} e^2\text{fm}^2$ or $B(E1) = 1.7(4) \times 10^{-5}$ W.u. is found for the 263-keV γ ray. $E1$ decays are typically hindered by a factor of $10^4 - 10^5$ with respect to their Weisskopf estimates, so the reduced transition probability is close to that which might be expected for a decay from an intrinsic state in this nucleus.

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