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Along the N=126 closed shell: study of ^{205}Au through its $\pi h_{11/2}^{-1}$ isomeric decay

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Abstract:

Excited states have been identified in only three of the N=126 closed shell nuclei 'below' ^{208}Pb: ^{207}Tl, ^{206}Hg and very recently ^{204}Pt. We aim to extend our knowledge of the neutron-rich N=126 nuclei by observing the internal decay of the $\pi h_{11/2}^{-1}$ excited state in ^{205}Au, which is expected to be isomeric. In addition, the decay of the analogous states in the N=122 and N=124 ^{201,203}Au will be studied. The lifetimes of the expected isomeric states are crucial for the success of the experiment, and they are estimated to be in the range of 0.3-20 s. These are long enough to enable the extraction from the source, but shorter than the beta-decay halflives. Proton single-particle energies and transition rates will be extracted, providing information about the robustness of the N=126 shell-closure. Three days of beamtime is requested.

1. Introduction and motivation

The understanding of how shell structure arises and develops is a major goal in nuclear physics. Nuclei close to the stability line exhibit magic numbers at proton and neutron numbers of 2, 8, 20, 28, 50, 82, 126 etc. By exploring the properties of neutron-rich nuclei it is known that the well established shell structure changes. Evidence for such effects has been observed for N=8,20,28,50 and even 82 [1]. These changes (shell quenching) are generally understood to come from a reduction of the spin-orbit splitting, in other words the Woods-Saxon potential changes towards a harmonic-oscillator type. No such effects have been observed or predicted so far for the N=126 nuclei.

^{208}Pb with 82 protons and 126 neutrons is a classic shell model core. The present proposal aims to investigate the robustness of the N=126 closed shell, by studying long-lived isomeric decays in neutron-rich gold isotopes.

Information on the neutron-rich N=126 nuclei is very scarce. Below the doubly magic ^{208}Pb nucleus there is experimental information on only four isotones: ^{207}Tl, ^{206}Hg, ^{205}Au, ^{204}Pt. While in ^{207}Tl [2], ^{206}Hg [3] and ^{204}Pt [4] excited states have been observed (including isomeric states, see fig. 1), in ^{205}Au only the ground state is known (I^{π}=(3/2$^+$) [5]).

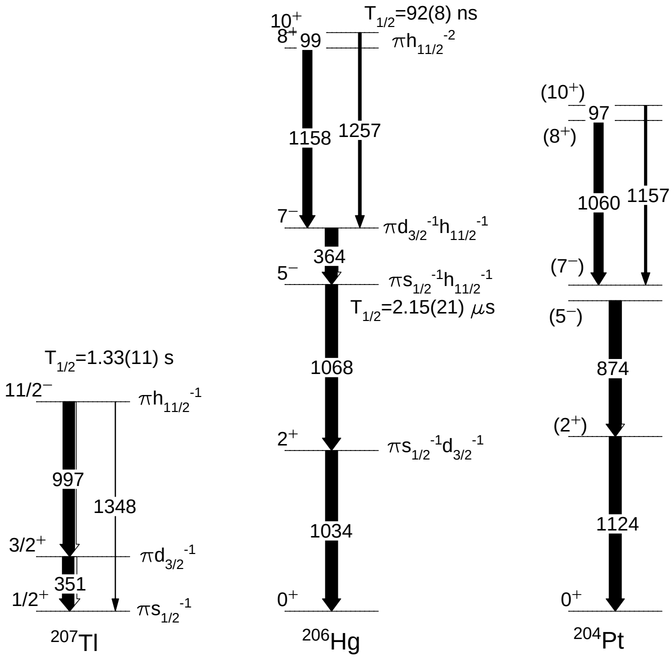

Figure 1: Partial level schemes of the neutron-rich N=126 nuclei ('below' ^{208}Pb) showing the isomers and the states populated by their decay [2, 3, 4]. The configurations of the levels are given. In the N=126 ^{205}Au nucleus an isomer with the same configuration as in ^{207}Tl, $\pi h^{-1}_{11/2}$ is expected. For ^{204}Pt a preliminary level scheme obtained from a recent (March 2006) GSI-RISING experiment is shown [4].

The lack of information on nuclei 'below' ^{208}Pb is due to the difficulties in populating these neutron-rich nuclei. However, spallation has proved to be an efficient tool to produce exotic nuclear species. When it is combined with high sensitivity gamma detection arrays, structure information can be gained for otherwise inaccessible nuclei. The present proposal seeks to obtain nuclear structure information on ^{201,203,205}Au nuclei, with N=122,124,126, respectively.

The low energy level scheme of the N=126, Z<82 nuclei are determined by the single proton orbitals below the Z=82 closed proton shell. The level scheme of ^{207}Tl, see fig. 2., illustrates well the single-proton orbitals which play a role, $\mathrm{s}_{1/2}$, $\mathrm{d}_{3/2}$ and $\mathrm{h}_{11/2}$, and also their relative energies. While in its groundstate ^{207}Tl has $\pi\mathrm{s}^{-1}_{1/2}$ configuration, ^{205}Au has $\pi\mathrm{d}^{-1}_{3/2}$ configuration. The proposed experiment will obtain information on the single proton energies below Z=82 and transition rates for the $\pi\mathrm{h}^{-1}_{11/2} \rightarrow \pi\mathrm{d}^{-1}_{3/2}$ transition (and maybe also for $\pi \mathrm{h}_{11/2}^{-1} \rightarrow \pi \mathrm{s}_{1/2}^{-1}$).

Partial level schemes for the ^{201,203,205}Au nuclei are shown in figure 2. In ^{205}Au only the ground state is known, with spin-parity ($3/2^+$) [5]. The level structure of ^{201,203}Au has been studied in (t,α) reactions [6, 7]. The $\pi h_{11/2}^{-1}$ states have been identified with a precision of 5 keV. Since these states can decay only via M4 and E5 transitions, with transition strengths expected to be close to one Weisskopf unit, these states should be isomeric. In all three nuclei, ^{201,203,205}Au, the $\pi h_{11/2}^{-1} \rightarrow \pi p_{3/2}^{-1}$ transition is expected to be dominant (except that we don't know whether there is a state at 549(5) keV in ^{201}Au and its spin-parity). We note that recently in ^{203}Au a 563 keV transition with a lifetime of $T_{1/2}=40^{+7000}_{-20}$ μs has been observed [10]. However this does not fit with the known excited states of [7].

The lifetimes of these isomers are crucial for the success of the experiment. Ideally they should be long enough to allow the extraction of the ions from the source, but shorter than the beta-decay half-lives of the nuclei of interest and contaminants (see section 2). The B(M4) value of the $\pi h_{11/2}^{-1} \rightarrow \pi p_{3/2}^{-1}$ transition is known in ^{197}Au to be B(M4)=2.4(8) W.u. [8]. Assuming the same strength in ^{201,203}Au, the estimated lifetimes are of $T_{1/2}$ ≈21 s and $T_{1/2}$ ≈13 s respectively. The lifetime of the $11/2^-$ state in ^{205}Au depends strongly on the unknown excitation energy ($\sim E^9$) of this state. For example it is estimated to be $T_{1/2}$ ≈6.3 s for E_x=700 keV and $T_{1/2}$ ≈0.33 s for E_x=1000 keV. (Similar lifetime estimates are obtained if we consider the B(M4)=3.2(3) W.u. transition strengths measured in ^{207}Tl [9].)

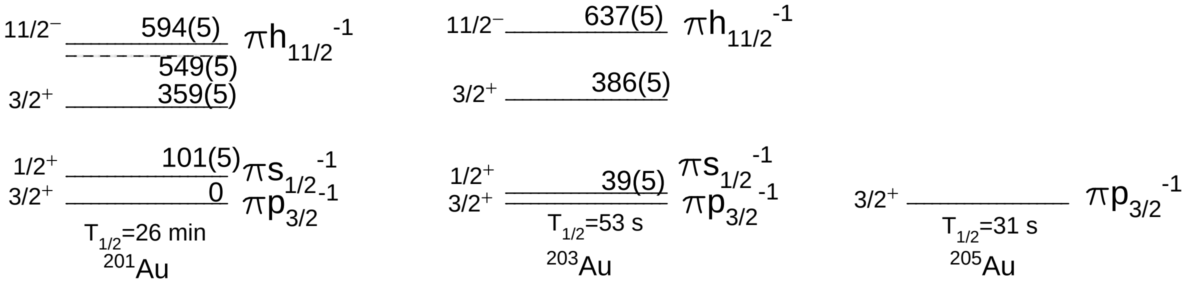

Figure 2: Partial level schemes of ^{201,203,205}Au [6, 7, 5]. The configuration of the levels are indicated.

As mentioned earlier information on the excited states of ^{204}Pt has been obtained from a GSI-RISING experiment performed in March 2006. The same experiment populated the ^{205}Au nucleus. However, the used experimental technique is not sensitive to isomeric decays with lifetimes longer than 1 ms, therefore ^{205}Au could not been studied.

2. Experiment

A letter of intent (CERN-INTC-2005-020, INTC-I-060) asking for the development of gold beams have been submitted to the INTC about one year ago. Since then the ionisation scheme for gold using the selective laser ion source has been successfully developed [11]. The ^{201,203,205}Au nuclei will be produced by bombarding the ISOLDE UC$_x$

target with a high-energy, high-intensity proton beam. The ions of interest will be extracted from the source and accelerated to 60 keV.

The Silberberg-Tsao cross-section database was used to estimate the in target production of gold isotopes (ISOLDE UCx target, 1.4 GeV protons). While gold is not the most volatile element, beacause the long halflives (>31s), full extraction from the targets could be assumed. RILIS efficiency is 3% [11]. The maximum beam intensities achievable with a 2.2 μA primary proton beams are: 2x105 ion/s for ^{205}Au, 5x10^5 ion/s for ^{203}Au and 1x10^6 ion/s for ^{201}Au. We can assume that about 10% of the gold nuclei will be in their isomeric state (the isomeric ratio is larger, but there will be losses due to the shorter lifetimes). The in target production of the less neutron-rich isobars is larger, so, beacuse of rate limitations in the detectors it is unlikely that we can take advantage of the whole beam intensity.

After mass separation (HRS) the ions will be implanted in a tape. The GSI tape system will be used, which allows for the detection of both gamma-rays (Ge detector) and conversion electrons (mini-orange spectrometer). The same tape system will be used at ISOLDE for a Valencia lead experiment in the summer of 2006 (IS398). The electron detector will be used to determine the electron conversion coefficient, and therefore prove the character of the transition (α(M4,700 keV)=0.46).

We expect that the lifetimes of the isomeric decays in ^{201,203,205}Au will be of the order of 0.3-20 s. These are shorter than the beta-decay lifetimes of the isobars (for example, the A=205 isobars have the following lifetimes: $T_{1/2}$=31s for ^{205}Au, 5.2 min for ^{206}Hg, stable ^{205}Tl, 10^7 y for ^{205}Pb etc.) Therefore the tape system will be used to remove the long-lived beta-decaying nuclei. The beta decays of the nuclei of interest have been previously studied [6, 5].

It is expected that the γ-ray detection efficiency is about 2% and the electron detection efficiency is 5%. The energies of the gamma rays expected to depopulate the isomers are about 600 keV. The needed beamtime depends drastically on the amount of isomaric contaminants in the beam. Considering this, time needed for optimising the mini-orange **three days of beamtime is requested.**

Table 1: Information about target, ion source and beam intensity for the three gold isotopes to be studied.

Beam	Min. Intensity	Target material	Ion source	Shifts
^{201}Au	10^0–10^5 ion/s	UCx	RILIS	3
^{203}Au	10^0–10^5 ion/s	UCx	RILIS	3
^{205}Au	10^0–10^5 ion/s	UCx	RILIS	3

3. Outlook

After the study of ^{205}Au, proposed here, it would be logical to continue the research on the robustness of the N=126 shell-colure with the next N=126 nucleus where no experimental information is available, namely ^{203}Ir. It is expected that ^{203}Ir has the same low energy structure as ^{205}Au: $\pi d_{3/2}$ groundstate, $\pi s^{-1}_{1/2}$ and $\pi h^{-1}_{11/2}$ lowest excited states.

Therefore the $\pi\mathrm{h}_{11/2}^{-1}$ excited states should be isomeric. The systematic of the N=126 odd-Z nuclei suggest that the energy of the $\pi h_{11/2}^{-1} \rightarrow \pi p_{3/2}^{-1}$ transition decreases with Z (997 keV in ^{207}Tl, 600–700 keV in ^{205}Au). This is consistent with what we know for Ir isotopes: ^{197}Ir is the most neutron-rich Ir nucleus where data is available, and the energy difference is 115(5) keV, and the lifetime is 8.9(3) minutes [12]. On the other hand this energy is inreases as we approach N=126: 80 keV in ^{193}Ir, 100(5) keV in ^{195}Ir and 115 (5) keV in ^{197}Ir. The isomer decay technique could give important information on the single-proton orbitals in this neutron-region by studying the isomeric decays in ^{199,201,203}Ir isotopes. Lifetimes in the minutes-seconds region are expected.

The production yield for ^{203}Ir is likely to be about 100 times lower than for ^{205}Au, but even so the experiment should be still feasable (the technique should work for beam intensities as low as 1 ion/s). The development of Ir beams could be considered.

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