EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Proposal to the ISOLDE and Neutron Time-of-Flight Committee

Coulomb excitation of the two proton-hole nucleus ^{206}Hg

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Abstract

We propose to Coulomb excite the single magic two-proton-hole nucleus ^{206}Hg. In single-step excitations both the first 2^+ and the highly collective octupole 3^- states will be populated. Thus, information on both quadrupole and octupole collectivity will be gained in this neutron-rich nucleus. Due to the high beam intensity, we will be able to observe multi-step Coulomb excitations as well, providing further test on theoretical calculations. The results will be used to improve the predictive power of the shell model for more exotic nuclei as we move to lighter N=126 nuclei.

The experiment will use the new HIE-ISOLDE facility and the MINIBALL array, and will take advantage of the recently developed ^{206}Hg beam from the molten lead target.

Requested shifts: 15 shifts

Beamline: MINIBALL + CD-only

Motivation

^{208}Pb with 82 protons and 126 neutrons is a classic shell model core. The present proposal aims at investigating the proton single particle states and their interactions below Z=82, and indirectly the robustness of the N=126 closed shell, by studying the two proton-hole nucleus ^{206}Hg. Transition strengths will be measured, and new levels will be established.

Information on the neutron-rich N=126 nuclei is scarce. Below the doubly magic ^{208}Pb nucleus there is experimental information on five isotones: ^{207}Tl, ^{206}Hg, ^{205}Au, ^{204}Pt and ^{203}Ir. In the most neutron-rich ones, ^{205}Au, ^{204}Pt and ^{203}Ir, all the available experimental information is from isomeric decays. In the Z=81 ^{207}Tl the highest known spin is 11/2 ($h_{11/2}$ proton hole state) [Kondev11]. The most comprehensive level scheme of ^{206}Hg was established from the ^{238}U+^{208}Pb deep-inelastic reaction [Fornal01]. Other studies were using (t,p) reactions [Becker82, Maier84] and isomeric decay following projectile fragmentation [Steer08].

The low energy level schemes of the N=126, Z<82 nuclei are determined by the single proton (hole) orbitals and their interactions below the Z=82 closed proton shell. The level scheme of ^{207}Tl, see fig. 1., illustrates the single-proton orbitals which play a role, $s_{1/2}$, $d_{3/2}$, $h_{11/2}$ and $d_{5/2}$, and also their relative energies. The experimental level scheme of ^{206}Hg is also shown in fig.1. The dominant configurations are indicated. Only yrast states are known. The ground-state has $\pi s_{1/2}$ configuration. The first excited states, with spin-parity 2^+, has $\pi s_{1/2}\, d_{3/2}$ configuration. The higher lying states, 5^-, 7^-, 8^+, 10^+, all have at least one $h_{11/2}$ proton hole in their configuration. No 3^-, 4^+ and 6^+ states are known, as these are non yrast.

In order to have a better understanding of the low-spin structure of ^{206}Hg shell model calculations have been performed. The OXBASH code [Brown04] was employed. The model space considered consisted of the proton orbitals $s_{1/2}$, $d_{3/2}$, $h_{11/2}$, $d_{5/2}$ and $g_{7/2}$ below the Z = 82 closed shell. Therefore, no core excitations across the ^{208}Pb double-shell closure are allowed. The single proton-hole energies are taken from the experimental spectrum of ^{207}Tl. The two-body interaction matrix elements (TBMEs) are from ref. [Rydstrom90]. They are based on the Kuo-Herling interaction [Kuo71] including core polarisation, with decisive elements adjusted to the experimental data available at the time. The standard proton effective charge, eproton=1.5e, was considered. This parametrisation is known to describe reasonably well both the known excited state energies and transition strengths in N=126 nuclei ^{206}Hg, ^{205}Au, ^{204}Pt [Steer11].

The nuclei around ^{208}Pb are characterised by large octupole collectivity due to the coherent contribution of several $\Delta l = \Delta j = 3$ particle-hole excitations available in this nuclear region. E.g.,the lowest energy state in ^{208}Pb is the collective 3^- octupole state at 2614 keV with $0^+ \to 3^-$ strength of 0.611(9) e^2b^3 (B(E3;3^-->0^+)=33.8(6) W.u.) [Martin07]. Similar collective 3^- states were observed in the mercury isotopes. The heaviest mercury isotope where this state was observed is ^{204}Hg, where the 3^- is at 2675 keV and has 0^+->3^- strength of 0.40(3) e^2b^3 (B(E3; 3^-->0^+)= 22(3)W.u.) [Chiara10]. Such a state is expected also in ^{206}Hg. Due to its collective nature, the energy of this state, as well as the B(E3) strength cannot be calculated with our shell model. We expect it at around 2.7 MeV with similar B(E3) like in ^{208}Pb and ^{204}Hg. The systematic of the collective B(E3) strengths in lead, mercury and platinum isotopes is shown in figure 2.

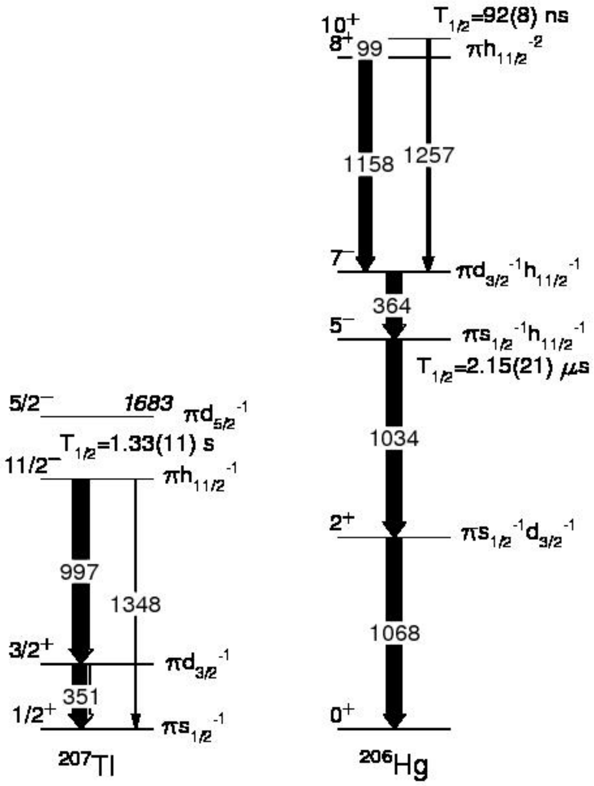

Fig.1.(Left): Single particle states in ^{207}Tl [Kondev11]. *(Right):* Level scheme of ^{206}Hg [Fornal01]. (Note that there are additional excited states know on the top of 10^+ which are not shown here.)

In order to understand which states will be populated in a low-energy multi-step Coulomb excitation, the transition strengths were also calculated. The possible levels to be excited are shown in figure 2. Two 2^+ states are expected to be strongly excited, the yrast 2^+ with $\pi s_{1/2}d_{3/2}$ configuration and the third 2^+ with $\pi s_{1/2}d_{5/2}$. The strengths going into $\pi d_{3/2}$ and $\pi h^2_{11/2}$ 2^+ states are orders of magnitude weaker. The 2^+ with $\pi d^2_{3/2}$ configuration will decay into the 0^+ with the same configuration. The yrast 4^+ $\pi d_{3/2}d_{5/2}$ state will be reached via the yrast 2^+ as two-step excitation. The calculations indicate that the yield of the 4^+->2^+ transition will be around 2% of that of the yrast 2^+->0^+. Three step excitations would populate the second 4^+ and the yrast 6^+ with $\pi h^2$11/2 configurations, but the yield will be only about $2x10^{-5}$ compared to the 2^+ -> 0^+ transition.

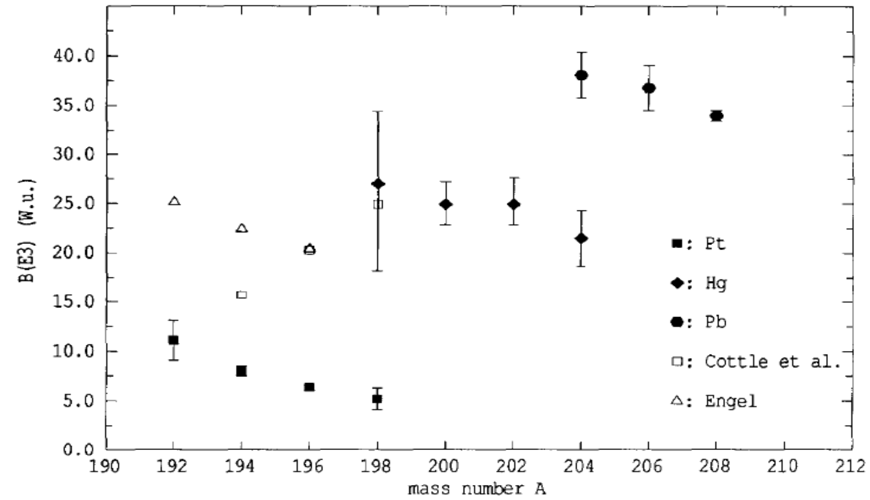

Fig.2. Systematics of the measured collective B(E3) transition strengths in Pt, Hg and Pb isotopes, taken from [Lim91].

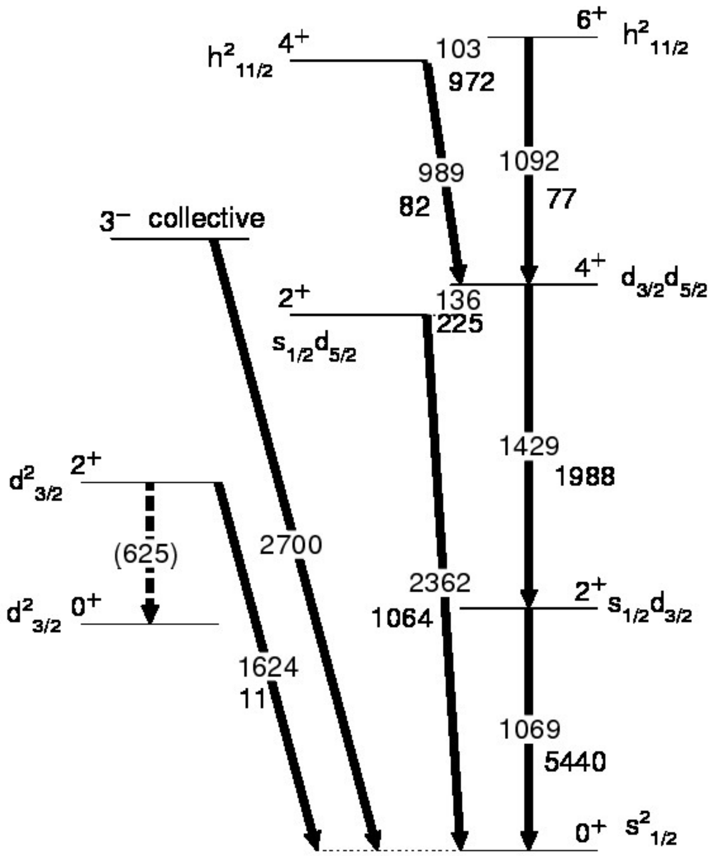

Fig.3. Shell model calculation showing levels expected to be populated via Coulomb excitation in ^{206}Hg. The numbers below the transition energies indicate the B(E2 UP) strengths in units of e^2fm^4. (All **bold** arrows should point up, not down). The dominant configurations are indicated. The energy of the collective 3^- state is from systematic and is expected to have a B(E3 UP) strengths in the order of 0.5 e^2b^3. The dashed arrow indicates that the second 2^+ states decays into the second 0^+.

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. Here we capitalise on the newly developed ^{206}Hg beam from the molten lead target. We note that an experiment to Coulomb excite ^{206}Hg at relativistic energies is approved at GSI within the AGATA campaign and is scheduled for the beginning of October 2012. At relativistic energies only 2^+ states are populated, practically there are no multi-step Coulomb excitation reactions.

The results obtained in the present experiment will be used to improve the predictive power of the shell model for more exotic nuclei as we move to lighter N=126 nuclei.

Experimental details

The ^{206}Hg beam will be delivered from the newly developed molten led target. During tests performed in 2011, 8×10^7/µC of ^{206}Hg was obtained from the Pb463-VD5 unit. On these units, one can take about 0.5 µA proton intensity on average, so that this translates into 4×10^7 pps ^{206}Hg. We can assume a (minimum) 3% overall transmission for post-acceleration. This gives a maximum ^{206}Hg beam intensity of 1.2×10^6 pps at MINIBALL.

A beam purity of 50% is expected. The other half of the beam will be ^{206}Pb from the natural lead target. The ^{206}Pb and ^{206}Hg beams cannot be separated using REXTRAP (too high beam intensity). It is likely that the rate on the Si detectors will be too high when all available beam is taken. There are no overlapping gamma-ray energies in ^{206}Pb and ^{206}Hg (at least from how much is known). On the positive side, the 0^+->2^+ transition strength is known in ^{206}Pb to be 0.101(3) e^2b^2, corresponding to B(E2; 803 keV;2^+ ->0^+)=2.80(9) W.u [Kondev08]. This can be used for calibration and cross checks. In order to understand the effect of the contaminant, we might need to run for some time without protons on the target; in this case the beam is composed by ^{206}Pb only.

The MINIBALL array will be used for gamma-ray detection and the CD Si detector covering 16-53° for charged particles. In order to distinguish between the ^{206}Hg and the recoiling target nucleus, there must be a large difference between their masses. Therefore it is envisaged that ^{120}Sn (E(2^+)=1171 keV) will be used as target. The same target was used for previous heavy ion Coulomb excitations at REX-ISOLDE. GOSIA [Czosnyka 83] calculations were performed considering the maximum safe Coulomb excitation beam energy of 845 MeV and a target thickness of 2 mg/cm^2. Assuming a conservative average ^{206}Hg beam intensity of 2×10^5 pps and 8% gamma-ray detection efficiency, the following transitions will be observable. (Note: all this is based on the shell model calculation!)

The yield for the 2^+->0^+ transition is expected to be around 0.1 s^{-1}= 9000 day^{-1}. For the 4^+->2^+ and the 3^- ->0^+ transitions the yields are 170 day^{-1} and 45 day^{-1}, respectively. We also expect to see the depopulation of the third 2^+ state with a yield of ~50 day^{-1}.

Summary of requested shifts: 15 shifts (5 days) of beam-time are requested. This does not include the time needed to set up HIE-ISOLDE.

References:

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *(name the fixed-ISOLDE installations, as well as flexible elements of the experiment)*

Part of the Choose an item.	Availability	Design and manufacturing
MINIBALL + only CD	☒ Existing	☒ To be used without any modification
[Part 1 of experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[Part 2 experiment/ equipment]	☐ Existing	☐ To be used without any modification ☐ To be modified
	☐ New	☐ Standard equipment supplied by a manufacturer ☐ CERN/collaboration responsible for the design and/or manufacturing
[insert lines if needed]		

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed MINIBALL + only CD installation.

Additional hazards:

Hazards	*[Part 1 of the experiment/equipment]*	*[Part 2 of the experiment/equipment]*	*[Part 3 of the experiment/equipment]*
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	[magnetic field] [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)			
Beam intensity			

Beam energy			
Cooling liquids	[liquid]		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			
Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			
Non-ionizing radiation			
Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			
Chemical			
Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		
Mechanical			
Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		
Noise			
Frequency	[frequency],[Hz]		
Intensity			
Physical			
Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

… kW