BARC–TIFR Pelletron Linac Facility Beam Time Request @2024

Title of the Experiment: Search for high-spin isomers and shears band in odd-odd ^{206}At

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Local Collaborator / Spokesperson: Prof. R. Palit

Collaborators Name:

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Motivation of the experiment: Nuclear structure investigations in the close vicinity of shell closures are mainly understood in the framework of shell model, while mid-shell nuclei are subjected to explain by different collective models. The nuclei lying between these two extremes, known as transitional nuclei, are of particular interest as interplay between the two modes of excitations results in diverse structural phenomena. ^{206}At lies at the lower boundary of the transitional region ($Z > 82$, $N < 126$). Several isomers have been reported in this region which mainly arise due to competition between the proton-particle and neutron-holes excitations. Study of such isomers is very important as they provide testing ground to various theoretical calculations. Moreover, presence of shears bands is another interesting aspect of the near-spherical nuclei in this region which aid in understanding of the shape evolution with increasing number of valence particles/holes. In the proposed experiment, we plan to search for high-spin isomers and shears band in odd-odd ^{206}At. These investigations and their comparison with the properties of neighboring At isotopes will provide insights into the shape evolution as one moves away from the neutron shell closure in At isotopes.

Beam details: ^{18}**O** beam with energy ranging between **88–95 MeV** and **1-2 pnA** beam current, Beam Port: **Hall2-15**

Or

^{13}**C** beam with energy ranging between **66–74 MeV** and **1-2 pnA** beam current, Beam Port: **Hall2-15**

Buncher requirement: Yes

Number of shifts (1 shifts=8 hr.) required: 21

Experiment details:

1. Objective of Experiment:

Nuclear structure studies in the proximity of the doubly shell-closure at N = 126 and Z = 82 are of particular interest to investigate single-particle excitations and extreme examples of nuclear isomers [1,2]. The metastable states represent the manifestation of the associated wave functions being pure and quite distinct from those of other levels in their vicinity, mainly attributed to the competing proton and neutron excitations. Thus, study of nuclear isomers provides opportunities to test the predictions of large-scale shell model with available interactions. Also, the near-spherical nuclei with a very small deformation and a few valence protons-particles and neutron hole are expected to exhibit shears band structures as commonly known in lighter Pb isotopes [3]. **In this proposal we plan to search for high-spin isomers as well as shears bands in the odd-odd ^{206}At (Z = 85, N = 121).**

Below are the objectives of the proposed experiment:

I. **Search for an unknown low-energy (7^+) → (5^+) transition.** Here, (5^+) states is the proposed ground state of ^{206}At. Measurement of this low-energy transition is very important to firmly determine the excitation energies of the subsequent higher-lying states in the level scheme. In addition to this, extension of the level scheme of ^{206}At up to high excitation energy and angular momentum and firm spin-parity assignments of the known excited states is one of the objectives of the proposed experiment.

II. Search for high-spin isomers with $T_{1/2}$ ranging between **few ns to few μs**.

III. Search for shears band in the odd-odd ^{206}At, which will improve our understanding on the evolution of nuclear structure properties in At isotopes as the neutron shell closure is approached.

A large amount of nuclear structure information is available on nuclei with Z < 82 and N < 126 around doubly-magic ^{208}Pb, however relatively less information on nuclei with Z > 82 and N < 126 exists, particularity, in the odd-odd Bi-At-Rn nuclei in A ≈

200 region. It is mainly attributed to limited stable beam-target combinations, considerable fission background, and the limitations on the maximum possible angular momentum that could be imparted to the system. Also, the structure of the odd-odd nuclei are complex to study due to relatively large density of states. Fig. 1 shows the known level scheme of odd-odd ^{206}At as reported by X. C. Feng *et al.* [6]. It may be noted that the energy of the $(7^+) \rightarrow (5^+)$ low-energy transition is not known, which leads to an uncertainty (< 100 keV) in the reported excitation energies of all the levels shown in Fig. 1. Such a low-energy transition of 71.7 keV $(7^+ \rightarrow 6^+)$ is also present in ^{208}At [6]. We plan to determine this low-energy gap by using LEPS detectors in the detector setup with the array of clover HPGe detectors. This will lead to a more precise measurement of the excitation energies of the levels in the level scheme.

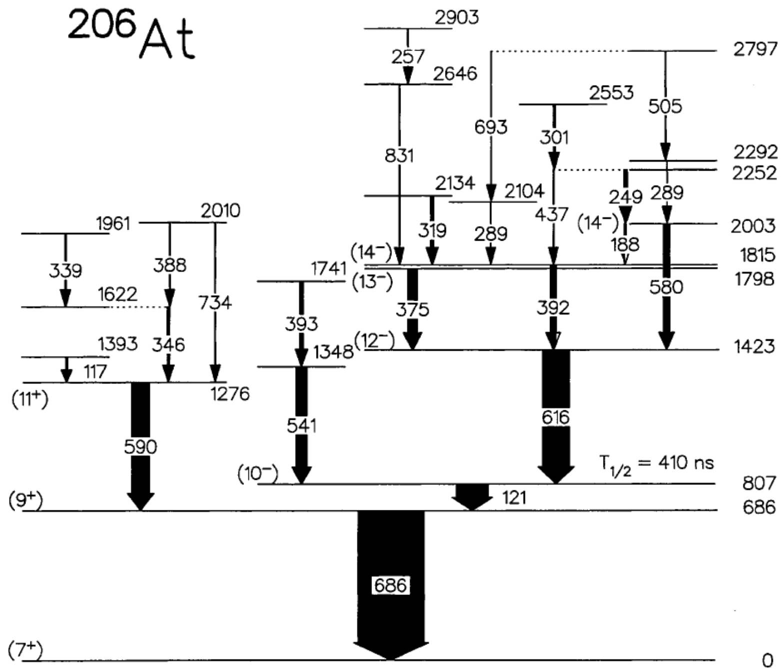

Fig. 1: Level scheme of ^{206}At as reported in Ref. [4].

Second objective of the proposed experiment is search for high-spin isomers in ^{206}At. The region around the doubly-magic ^{208}Pb is rich in nuclear isomerism [2]. A systematics of low-lying isomers in At isotopes is shown in Fig. 2. It may be noted that a two quasiparticle isomer, 10^- $[\pi(h_{9/2}) \otimes \nu(i_{13/2})^{-1}]$, is systematically observed in odd-odd At isotopes with N = 119–123 [4–6]. It may also be noted that the excitation energy of the 10^- state is decreasing with increasing neutron holes, which indicates increasing collective effects. Moreover, an isomeric three quasiproton state, $29/2^+$ $[\pi(h_{9/2}^2 i_{13/2})_{29/2+}]$, has been reported in all odd-A At isotopes with $114 \leq N \leq 126$ [7]. Further, it was observed that the corresponding isomeric states 16^+ $[\pi(h_{9/2}^2 i_{13/2})_{29/2+} \otimes \nu(i_{13/2}^{-1})]$ and 16^- $[\pi(h_{9/2}^2 i_{13/2})_{29/2+} \otimes \nu(f_{5/2}^{-1})]$ are known in ^{204}At and ^{206}At, respectively.

These observations suggest that the coupling of an unpaired neutron particle or hole with the $29/2^+$ isomer in odd-A At isotopes results in an isomeric state in corresponding odd-odd A isotopes. However, no such isomer is known in ^{206}At as shown in Fig. 2. It is very important to note that there is a competition between the $\nu(i_{13/2}^{-1})$ and $\nu(f_{5/2}^{-1})$ neutron configurations as one moves from ^{208}At to ^{204}At. Therefore, it is very interesting to investigate a similar isomer in ^{206}At, which lies at the transition point. The properties of this isomer are expected to provide more insights on the variation of single-particle energies of these neutron orbitals, which will be helpful in improving the available shell-model interactions to be used for more complex systems.

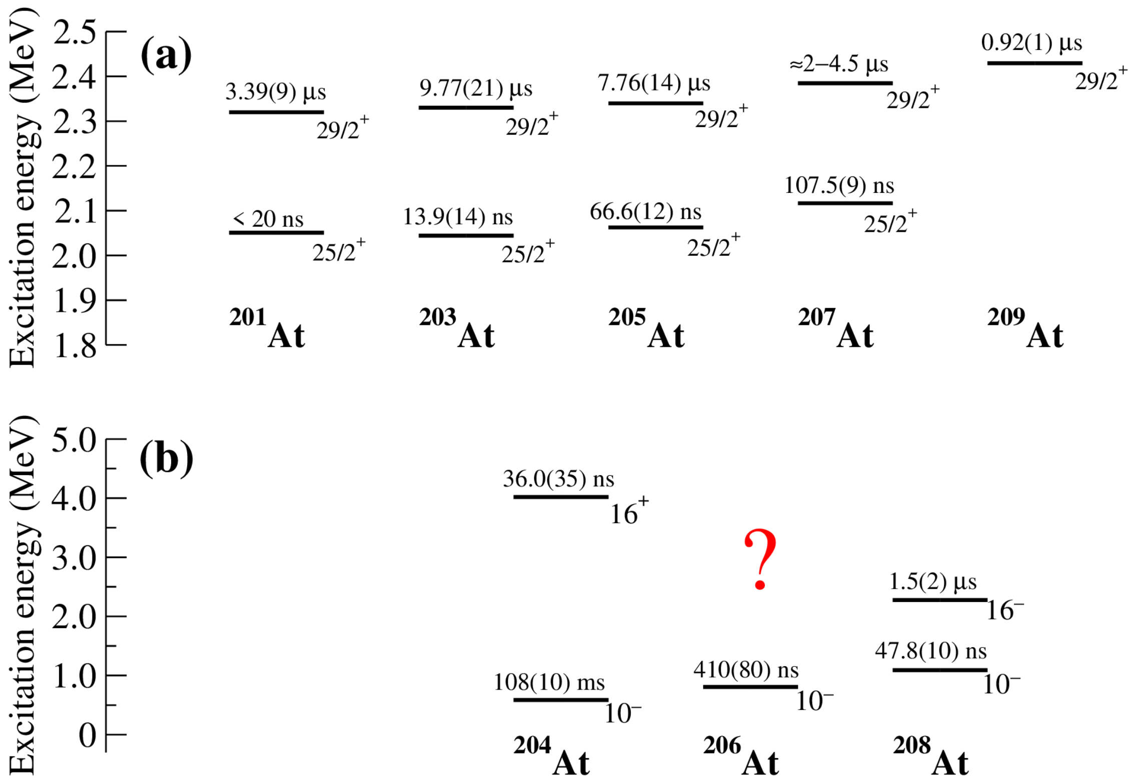

Fig. 2*:* Systematics of isomers in (a) odd-A and (b) odd-odd At isotopes.

Furthermore, a recent study by Wahid *et al.* [1] reported extreme examples of nuclear isomers in ^{205}Bi [$T_{1/2}$ = 8(2) ms], ^{204}Pb [$T_{½}$ = 0.22(2) ms], and ^{206}Bi [$T_{1/2}$ = 27(2) μs]. These isomers are identified as the longest-lived nuclear states in the nuclear chart at such a high excitation energy (>7 MeV) and indicate emergence of island of nuclear isomerism due to core excitations in high-excitation energy regime [1]. It will be very fascinating to search for such core-excited isomers in high-excitation energy regime in ^{206}At. Such metastable states are expected to provide discriminating tests of the effective interactions used in current large-scale shell-model calculations.

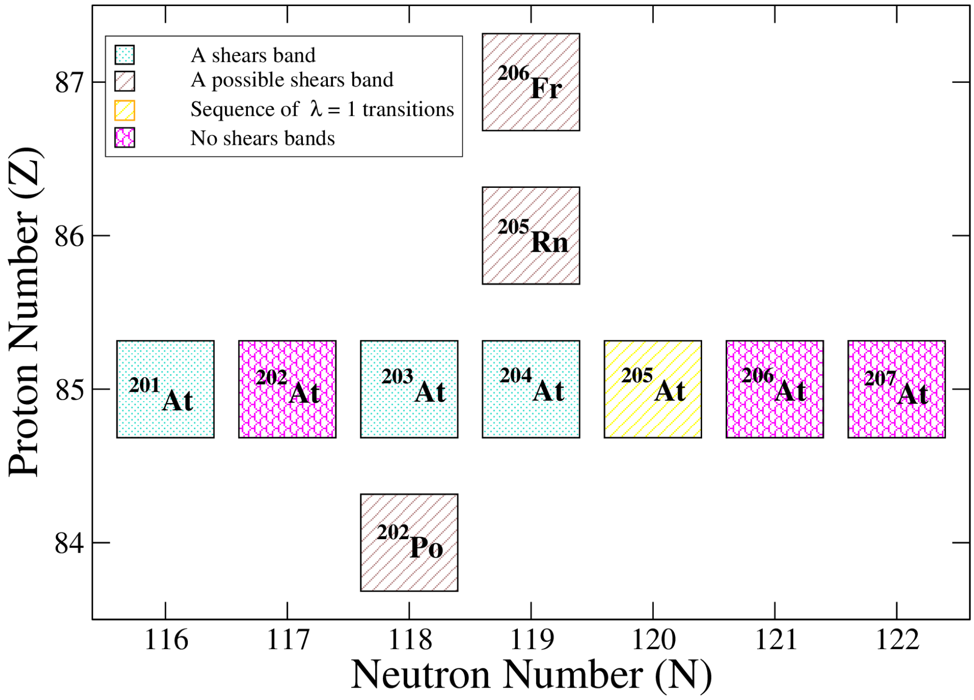

Fig. 3: Survey of shears bands in Po, At, Rn and Fr isotopes.

Moreover, the evolution of nuclear structure in the region with Z > 82 and N < 126 is also reflected in the shears-band structures observed in near-spherical nuclei in this region. Shears bands are signatures of weakly deformed near-spherical nuclei, which were reported in several nuclei in A ≈ 200 mass region [3]. Figure 2 depicts survey of shears bands in Po, At, Rn, and Fr isotopes. It may be noted that such structures have been observed in ^{201,203,204}At. Further, a sequence of ΔI = 1 transitions is reported in ^{205}At [8]. However, no such sequences were observed ^{207}At [7] and heavier At isotopes. Thus, the nucleus of our interest viz. ^{206}At lie at the boundary below which evidences of magnetic rotational bands have been reported in the At isotopes. Therefore, It will be very interesting to search for such structures in the ^{206}At, which will further aid in understanding the evolution of nuclear structure with increasing neutron holes in N = 126 shell closure.

2. Description of Experiment:

We propose to search for high-spin isomers and shears structures in ^{206}At by extending the level scheme. High-spin states of ^{206}At nucleus will be populated via **^{193}Ir(^{18}O,5n)^{206}At** reaction with beam energies between **88-95 MeV.** The predications of PACE4 calculations show that ^{206}At is the dominant channel in the proposed beam energy ranges in the reaction (see the Fig. 4), which will be very much helpful to unambiguous assignment of weak gamma rays to the odd-odd ^{206}At.

It may be noted that previous study of ^{206}At was performed fifteen years ago using seven HPGe detectors with BGO(ACS), and one planar detector. This work could establish excited states only up to ~ 14 ħ and E_x ≈ 2 MeV with firm spin-parity assignments. The beam time calculations for the proposed reactions and the PACE4 predictions for the cross-section (~350 mb) suggests that atleast **21 shifts of beam time** are required to firmly assign spin-parities of the high-spin states.

- The comparison of the available information on ^{206}At with the neighboring At and Po nuclei suggests several low-energy gaps in the level scheme. Therefore, the use of **two LEPS detectors in conjection with the array of clover HPGe detectors** will be helpful in firmly establishing the level scheme.
- Also, several isomers are expected in the level scheme. The use of the **LaBr3 detectors along with the array of clover HPGe detectors** will be useful in determining the lifetimes of few hundreds of picoseconds to few ns.

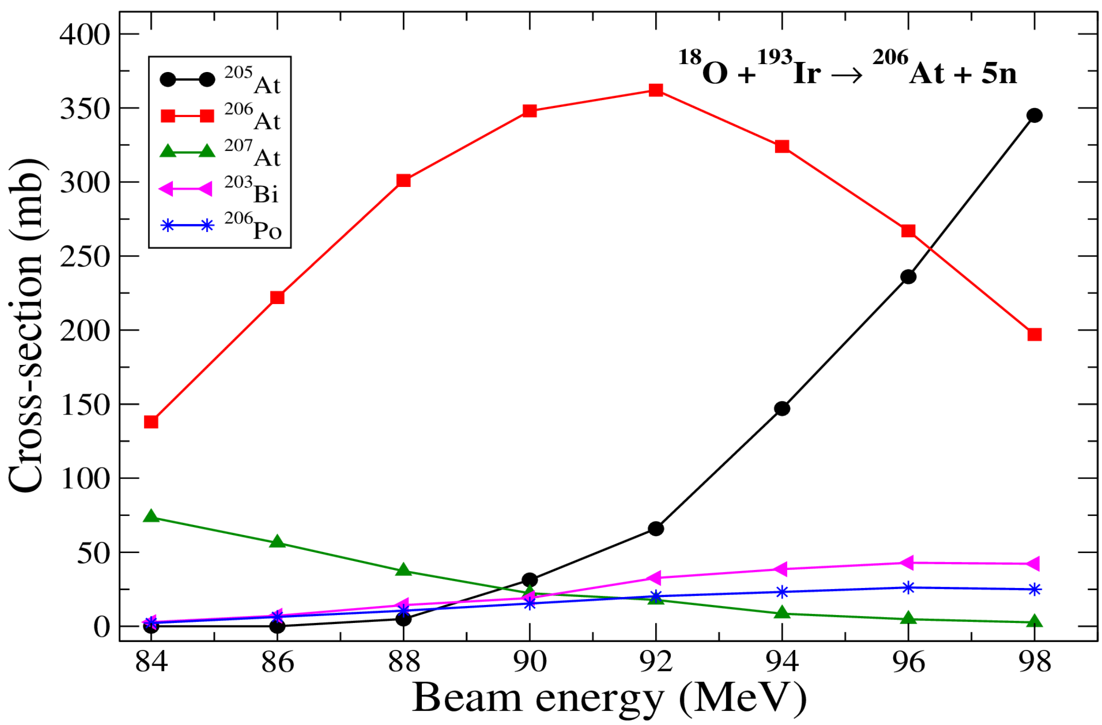

Fig. 4: Cross-section predications of PACE4 calculations for ^{18}O + ^{193}Ir reaction.

Alternate Reaction:

An alternate reaction to study ^{206}At is **^{197}Au(^{13}C,4n)^{206}At** with beam energies between **66–74 MeV.** A plot showing predications of PACE4 calculation is shown in Fig. 5.

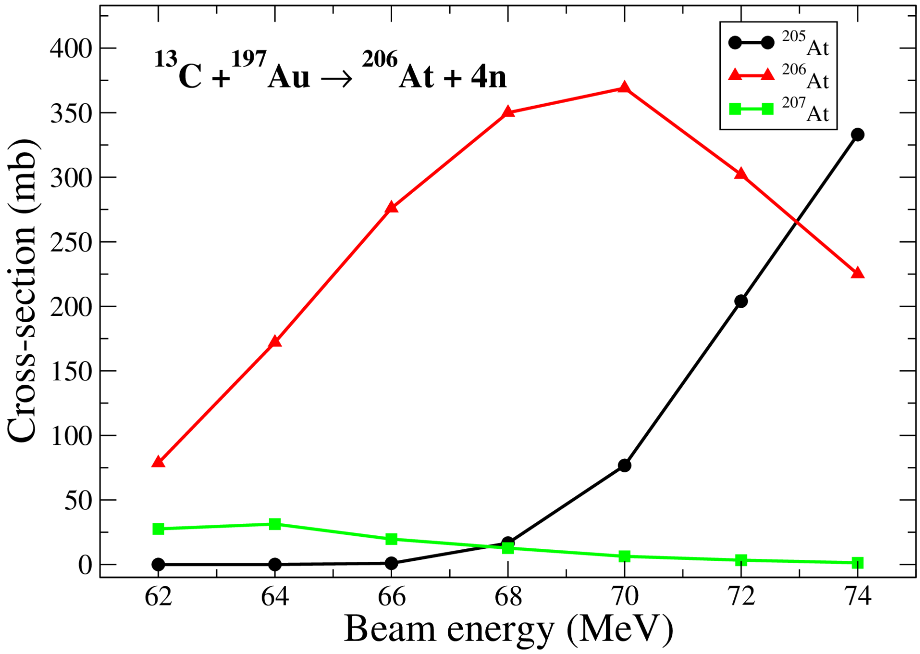

Fig. 5: Cross-section predications of PACE4 calculations for ^{13}C + ^{197}Au reaction.

Justification of Beam Time Requirement

Rate of production of residual nuclei (N_R):

N_R = 3.6*X-section(mb)*I(pnA)*t(μg/cm^2)/A_T

Here A_T = atomic mass of target material.
I = current

t = thickness

Number of n fold events recorded in per unit time N(n)

$N(n) = N_R * {}^{M}C_n * \epsilon^n * (1- \epsilon)^{(M-n)}$

where, M = gamma multiplicity, and Є= efficiency of array

Reaction: $^{193}Ir(^{18}O,5n)^{206}At$

Target thickness = 5 mg/cm^2, Cross-section for 5n channel ≈ 350 mb, Energy of the beam = 90 MeV, Efficiency of the INGA array with 18 clover detectors = 4%, Beam current (I) = 1pnA

Rate of production of residual nuclei (N_R) = 32642

Number of 2-fold events recorded per unit time ≈ 150 → **~ 10^7 events in 21 shifts**

References

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