сообщения
объединенного
института
ядерных
исследований
дубна

E13-94-198

B.A.Chernyshev[1], S.V.Dovgun, M.G.Gornov[1],
V.N.Grebenev[1], Yu.B.Gurov[1], S.L.Katulina,
V.G.Sandukovsky, R.R.Shafigullin[1]

SEARCH FOR DEEPLY BOUND PIONIC ATOMS WITH HIGH-PURITY GERMANIUM TAGGING SPECTROMETER

---

[1] Moscow Engineering Physics Institute, Kashirskoe sch.31,
Moscow 115409, Russia

1994

Up to now low-lying states of pionic atoms have been observed only for nuclei with $Z < 14$ for 1s and $Z < 35$ for 2p levels while the standard pionic nuclear optical potentials predict rather narrow widths of these levels of heavy elements [1,2]. Conventionally the spectroscopy of pionic atoms was done by stopping negative pions in a target and observing pionic X-rays emitted during the cascade. However for large Z the absorption widths of low-lying levels are around some orders of magnitude larger than electromagnetic one and therefore cascade X-transitions are very difficult to observe. Now new reactions appropriated for observation of deeply bound pionic atoms are proposed [3-11].

At TRIUMF such states were searched in the reaction $^{208}\mathrm{Pb}(n,p)^{208}\mathrm{Pb}_{\pi^-}$. No positive evidence was observed [12]. To obtain better statistics with better resolution recently the reaction $^{208}\mathrm{Pb}(d,^2\mathrm{He})$ $^{208}\mathrm{Pb}_{\pi^-}$ at an energy of 1 GeV was measured at SATURNE [13]. Preliminary data analysis does not show any indication of the observation of deeply bound pionic atoms. Both experiments have reached the sensitivity of the PWIA prediction but theorists have found that distortion effects are important [12,14]. The reactions (π^-,p) and (π^-,γ) are under investigation at LAMPF [10,11]. Recently theorists have found the use of pick-up reactions, such as $^zA(n,d)^z(A-1)_{\pi^-}$, $^zA(p,2p)^z(A-1)_{\pi^-}$ and $^zA(d,^3\mathrm{He})^z(A-1)_{\pi^-}$ looks attractive [5,6]. Investigations of these reactions on Pb target are planned at TRIUMF, COSY and SATURNE correspondingly. Preliminary data on the $^{208}\mathrm{Pb}(n,d)X$ reaction ($T_d = 400MeV$) have been obtained [15]. Just below the free pion emission threshold somewhat strengthening the deuteron spectrum has been observed, but the beam resolution and statistics are obviously inadequate to search pionic states.

The detailed theoretical investigation of using the pick-up reaction $(d,^3\mathrm{He})$ for the formation of the deeply bound pionic atoms has been performed in [6]. In the framework of effective number approach it was shown that the cross section of the reaction $^zA(d,^3\mathrm{He})^z(A-1)_{\pi^-}$ reaches maximum magnitude in the energy interval T_d = 500 - 600 MeV. These energies correspond to minimum values of momentum transfer (q) and the largest values of the cross section of the elementary reaction $p(d,^3\mathrm{He})\pi^-$. It has been found that at these energies substitutional states ($[(l_{\pi^-}, j_n^{-1})J] \sim 0$) are preferentially populated (l_{π^-} and j_n are angular momentum of pionic state and pick- up nuclear neutron correspondingly). At the energy where $q = 0$ only pionic atom states with $l_\pi = l_n$ will be populated. This selection rule shows that at the recoilless conditions the study of 1s and 2p pionic states is favorable for nuclei near neutron "magic" numbers 82 and 126 correspondingly.

We intend to perform experimental search for the deeply bound pionic atoms of Xe in the two-body channels of the reaction $_N\mathrm{Xe}(d,^3\mathrm{He})_{N-1}\mathrm{Xe}_\pi$ - at a deuteron energy T_d = 500 MeV corresponding to recoilless kinematics of pionic atom production.The levels of pionic atoms will be identified by peaks in the ^{3}He energy spectrum measured at $\Theta = 0$ where the cross section must reach the largest value [16]. For this investigation an experimental set-up has to satisfy the following requirements: a good identification of ^{3}He with energy up to 370MeV, high energy resolution compared with width of pionic level (0.5MeV) and capability to handle count rates about 10^4 particles/s. It should be pointed out that this experiment and ones which are planned at TRIUMF, SATURNE and COSY on Pb target ($N = 126$) directed on search for the different states of pionic atoms — 1s for Xe and 2p state for Pb.

The scheme of the experimental set-up is presented in the Figure. The spectrometer consists of the semiconductor telescope located in the bending magnet of the CELSIUS storage ring at a distance about 6m after the internal gas target (it is not shown in the figure). The telescope allows one to detect and measure the energy of ejectiles (^{3}He) which are emitted in a forward direction with respect to primary beam and deflected by the bending magnet. To provide the operation of the spectrometer at a short distance (about few cm) from the beam, the experimental set-up contains of the automatic mechanical system. This system allows one to insert and place the telescope into ultra-high vacuum volume of the storage ring ($\sim 10^{-11}$ mbar) close to the beam in synchronism with accelerator cycle. This is important since the beam size is increased during its formation. The mechanical system consists of the guiding mechanism with high precision control servo-system and movable cryostat with circulated nitrogen cooling system located inside the bellows. This construction provides the movement of the telescope at a distance up to 65 cm with a maximum speed about 5cm/s. The position uncertainty is less than 0.1 mm.

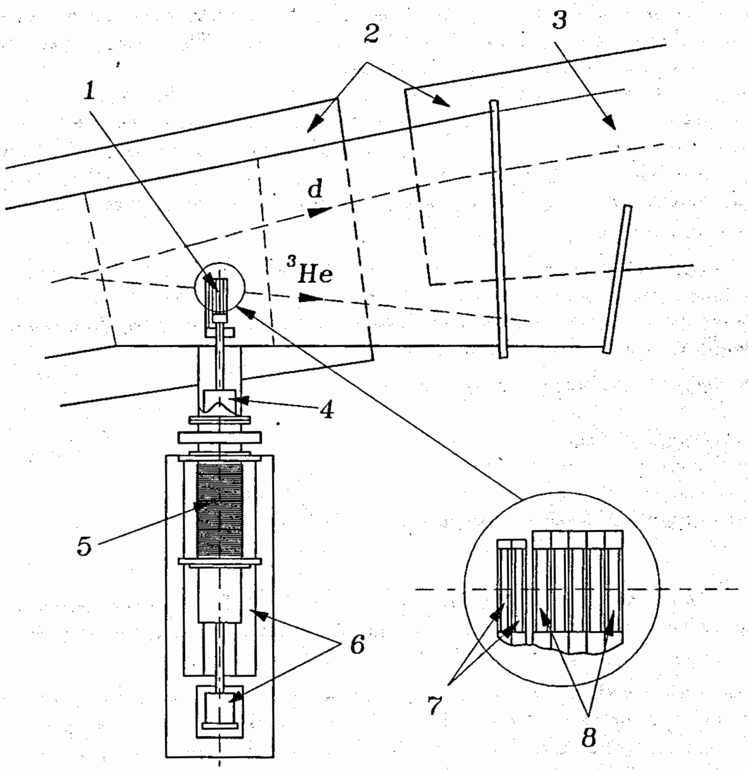

Fig. The scheme of experimental set-up:
1 - semiconductor telescope; 2 - dipoles; 3 - vacuum pipe; 4 - cryostat; 5 - bellows ; 6 - moving system; 7 - silicon strip detectors; 8 - HpGe-detectors

The telescope consists of five HpGe-detectors of total thickness of 4.5cm with sensitive area of about 10cm^2 and dead layers less than 100μm. The multilayer structure of the telescope provides good particle identification in wide energy range, simple energy calibration and the operation at high count rates (up to $10^5 s^{-1}$). In addition, it makes possible the effective solution of some problems concerned with the background suppression: analysis of signals from detectors on the level of fast logic system (fast trigger) provides almost full rejection of light ions (p, d, t with a rate of about 10^4 particle/s), and off-line analysis of energy losses allows one to reject events concerned with nuclear interactions in the telescope.

Two strip detectors of thickness about 500μm are used in front of the telescope. The coordinate system provides the measurement of spatial distribution of ejectiles and spectrometer efficiency. As follows from our preliminary simulation, the spatial resolution of the coordinate system should be about 1mm.

The main features of this set-up are:

- energy range for ^{3}He	- 30 - 370 MeV,
- sensitive area	- 10cm^2,
- energy resolution	- 200 keV,
- spatial resolution (pitch of strip detectors)	- 1mm.

The high energy resolution of the spectrometer, the high momentum resolution of the deuteron beam ($\Delta P/P < 10^{-4}$) and using of the internal gas target at CELSIUS allow the best accuracy of search for the deeply bound pionic atoms.

To estimate expected experimental rates and background we have performed preliminary simulation of this experiment. In the simulation we took into account the parameters of beam, target, magnetic structure of the CELSIUS ring and HpGe spectrometer. We used the estimation of cross sections of the pionic atom production from [6]. Using the cascade exciton model /CEM/ of nuclear reaction [17] we have obtained the estimation of the background induced by secondary charge particles in the d+Xe reaction (T_d=500MeV). We have obtained the following results:

- at luminosity L =$10^{31} cm^{-2} s^{-1}$ the experimental rate of pionic atom production is about $10^{-1} - 10^{-2}$ events/s.

- experimental rate of secondary ^{3}He is of the same order.

- the main contribution in background results from elastic scattering deuterons and can reach $10^4 s^{-1}$.

The experimental investigation may include three stages. Up to now the experimental data concerning the pick-up reaction (d,^{3}He) at excitation energy of residual nuclei $E_x \sim m_\pi c^2$ are absent [6]. To obtain preliminary data for the background estimation and test the spectrometer, we suppose to carry out the measurement on a cheap argon target using the existing cluster jet set-up without recirculation system. For extrapolation of these results for xenon target we assume to use simple theoretical estimations within the cascade exciton model. It should be noted that this information may be interesting in the study of the reaction mechanism.

At the second stage we assume to carry out the measurement of ^{3}He spectrum in the reaction $d+^{nat}$Xe $\rightarrow ^3$He + Xe at deuteron energy T_d = 500 MeV. As followes from our estimations of experimental rates, this experiment may be performed using existing cluster jet target. In spite of the fact that natural xenon is a mixture of isotopes, the results of our preliminary simulation of ^{3}He spectrum demonstrate that peaks corresponding to the pionic atom production may be observed but only rough estimations of the binding energy and width (with error δE ~1-2MeV) can be obtained. Nevertheless these experimental data will allow one to estimate the cross section (or its upper limit) of pionic atom production in the pick-up reaction and compare it with theoretical predictions.

At the last stage we propose to carry out measurements with pure isotope Xe target. This experiment will be carried out using a new gas-jet target with recirculation system intended for expensive gases which is under construction at CELSIUS. We assume that this experimental data will allow determination of binding energy and width of 1s level of Xe pionic atoms. Also we assume to perform measurements of the dependence of differential cross sections of the pionic atom production on the deuteron energy from 480 up to 520 MeV. This information may be important for the study of a mechanism of this reaction. To determine the magnitude of differential cross section in these experiments, we suppose to carry out measurements of the spectrum of ^{3}He produced in the reaction $p(d,^3\mathrm{He})\pi^\circ$ and normalize our results using the known cross section of the last reaction.

We expect that the proposed experiment will allow us to discover the production of the deeply bound pionic atoms of heavy elements, determine the magnitude of the cross section and parameters of 1s level of Xe pionic atoms.

This work is supported by the Russian Foundation of Fundamental Research.

References

[1] Toki H. and Yamazaki T., Phys. Lett. **B**, v.213(1988), p.129.

[2] Toki H. et al., Nucl. Phys. **A**, v.51(1989), p.653.

[3] Yamazaki T., Nucl. Phys. **A**, v.518(1990), p.213. The article has an extensive set of references.

[4] Nieves J. and Oset E., Phys. Rev. **C**, v.43(1991), p.1937.

[5] Toki H., Hirenzaki S., and Yamazaki T., Nucl. Phys. **A**, v.530(1991), p.679.

[6] Hirenzaki S., Toki H., and Yamazaki T., Phys. Rev. **C**, v.44(1991), p.2472.

[7] Yamazaki T. Hayano R.S. and Toki H., NIM, **v.A305** (1991), p.406.

[8] Nieves J. and Oset E., Phys. Lett. **B**, v.282(1992), p.24.

[9] Nieves J., Proc. of Int. Workshop on Pions in Nuclei, Peniscola, Spain, 1991, ed. by E.Oset, M.J.Vincente Vacas, and C.Garcia Recio, World Scientific, Singapore, 1992, p.355.

[10] Birbriar B.L. et al. This proposal is quoted and investigated in Kaufmann W.B., Siegel P.B. and Gibbs W.R., Phys. Rev. **C**, v.46(1992), p.1474.

[11] Seth K.K., Deeply bound pionic states in heavy nuclei. Experiment N1280, LAMPF.

[12] Iwasaki M. et al., Phys. Rev. **C**, v.43(1991), p.1099.

[13] Yamazaki T. et al., SATURNE proposal **N214**, 1988.

[14] Nieves J. and Oset E., Nucl. Phys. **A**, v.518(1990), p.617.

[15] Trudel A. et al., Experiment N628, TRIUMF. This data is quoted in T.Yamazaki, Nucl. Phys. **A**, v.553(1993), p.221c.

[16] Kazarnovskii M.V. et al., Proc. of Int. Workshop on Pions in Nuclei; [4], p.337.

[17] Gudima K.K. et al., Nucl. Phys. **A**, v.401(1983), p.329.