$^{4}He^{2+}$ AND H_2^+ ION BEAM SEPARATION ON "SOKOL" IBA FACILITY

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Two separation methods of $^{4}He^{2+}$ and H_2^+ ion beams have been tested on "Sokol" IBA facility of NSC KIPT: use of existing beam-bending magnet and electrostatic analyzer, dissociation of H_2^+ ions when the beam passes through the carbon film. It is shown that these methods allow to decrease essentially the H_2^+ ion content in the $^{4}He^{2+}$ beam.

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1. INTRODUCTION

Two types of injectors are used on "Sokol" electrostatic accelerator[1]: *RF ion source* for the production of single charged ions of gases and *Penning type ion source* with cold cathode and axial ion extraction system [2] for the production of multi-charged ions of gases. The multi-charged ion production on "Sokol" IBA facility expands analytical possibilities of developed ion beam analysis (IBA) techniques due to the depth analysis: Rutherford back scattering ions (RBS), elastic recoil detection (ERD) and nuclear reaction analysis (NRA); and expends the ion energy range for the irradiation beam line of the "Sokol" IBA facility. Protons, single and double-charged ^{4}He ions are mainly used for IBA techniques.

Since residual gas in the facility has hydrogen and hydrogenous gases, then H_2 ions are generated in the Penning ion source together with $^{4}He^{2+}$. The cross section of H_2^+ production is in $\sim 10^3$ times bigger than cross section of $^{4}He^{2+}$ [3]. Thereby, the H_2^+ and $^{4}He^{2+}$ ion beams currents could be equal by value and there is a problem of separation these beams.

2. METHODS OF BEAM SEPARATION BY MASSES

Only two methods of beams separation by masses are possible in our case: using magnetic mass spectrometer and H_2^+ ions dissociation in thin carbon foils with mass analyzer. As equipment beam line [4] has limits to use additional magnetic mass spectrometer, than possibility of H_2^+ and $^{4}He^{2+}$ beams separation using beam-banding magnet was chosen and examined.

The beam separation calculation [5] of two ion trajectories (H_2^+ and $^{4}He^{2+}$) after beam-bending magnet on specified distances (L) was made, according to the scheme presented in Fig.1.

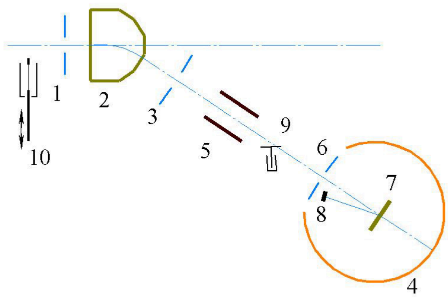

Fig.1. *Experiment of H_2^+ and $^{4}He^{2+}$ beam separation scheme on the beam line. 1 – slit 5 mm; 2 – mass analyzer; 3 – energy stabilization slit; 4 – experimental chamber; 5 – electrostatic analyzer; 6 – slit 0.9 × 9 mm²; 7 – Faraday cup or Ta target; 8 – surface-barrier detector; 9 – beam monitor; 10 – carbon foils device*

The results of calculations are distances (Δ) between these trajectories of ions H_2^+ and $^{4}He^{2+}$ after beam bending magnet. The values of these distances are shown in the Table.

The calculation results of distances between H_2^+ and $^{4}He^{2+}$ trajectories

Components of beam line (*Fig.*2)	L, m	Δ, m
Energy stabilization slit (3)	0.47	$0.96189 \cdot 10^{-3}$
Electrostatic analyzer (5)	0.635	$1.25265 \cdot 10^{-3}$
Input slit of targets chamber (6)	2.54	$4.25084 \cdot 10^{-3}$
Faraday cup (FC) or Ta target (7)	2.8	$4.66394 \cdot 10^{-3}$

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Thus, on the basis of the calculation one could say that the expected value of the distance between the peaks of H_2^+ and $^4He^{2+}$ ion beams in the chamber will be close to $4.6\,mm$.

3. EXPERIMENTAL CONFIRMATION OF H_2^+ AND $^4He^{2+}$ IONS SEPARATION

Study of H_2^+ and $^4He^{2+}$ separation was done by scheme shown in Fig. 1. Ion beam drifts to electrostatic analyzer (5) after beam-bending magnet (2).

Two methods of ion beam current measurements were used: direct measurement of beam current that drifts through slit by FC and back scattering He and H ions registration by surface-barrier detector from Ta target.

Scanning of ion beam on the slit (6) was achieved by changing the electric field intensity in electrostatic analyzer. In the first case the ion beam after electrostatic analyzer is drifted through collimator slit (6) and then to *Faraday cup* (7). Slit (6) has the following dimensions: $0.55 \times 9\,mm^2$. Ion current on FC was measured by device for measuring beam current [6] with scale up to $10\,nA$. In the second case, after electrostatic analyzer the ion beam is drifted through collimator slit (6) with dimensions 0.9×9 mm and then to the Ta target in the experimental chamber.

He and H back scattering particles were detected by surface-barrier detector (8). Detecting angle was equal to 170°. Total ion current on Ta target was monitored by ion beam monitor system (9). This system consists of beam chopper target of W and surface-barrier detector for back scattering ion registration from this target.

Tungsten is used as a target material for ion beam monitor because it is a refractory element with high atomic number and with the high ion back scattering cross sections respectively. W target rotates with frequency of $1\,Hz$ and relative time of ion beam overlapping is equal to 7%.

H_2^+ and $^4He^{2+}$ ion beam current measurements show (Fig.2,a) that FWHM of H_2^+ and $^4He^{2+}$ ion beams is close to $4\,mm$, and distance between two peaks is $\sim 4.5\,mm$. It means that beams have been separated.

RBS technique was used for more sensitive determination method of H_2^+ ion content in $^4He^{2+}$ ion beam. *Ortec-DE*-100 surface-barrier detector was used in these experiments with the following parameters: energy resolution is $13\,keV$ for energy alpha-particles $5.5\,MeV$; square is $50\,mm^2$ and depth of sensitive layer – $100\,\mu m$.

After RBS-spectra processing ^4He and H back scattering particles flow ratios were calculated. These flow ratios were recalculated to H_2^+ and $^4He^{2+}$ ion current ratios on Ta target. In the central part of $^4He^{2+}$ ion beam the H_2^+ ions were detected and $^4He^{2+}$ and H_2^+ ion current ratio is close to 27 (Fig.2,b).

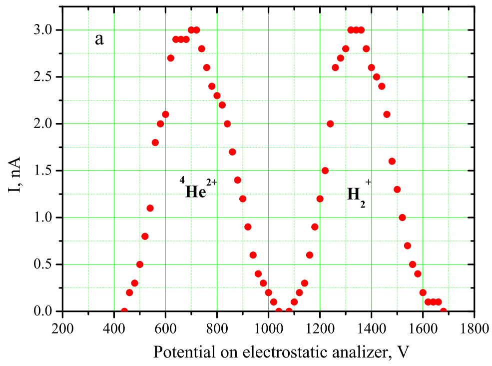

Fig.2a. *$^4He^{2+}$ and H_2^+ ion beam profiles*

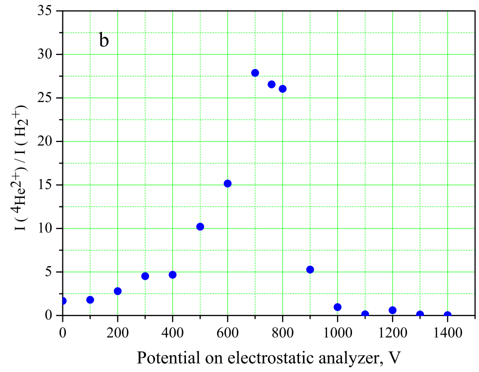

Fig.2b. *$^4He^{2+}$ and H_2^+ ion current ratio according to RBS*

Thus, the measurements show that the using of beam-bending magnet and electrostatic analyzer allows to separate the $^4He^{2+}$ and H_2^+ ion beams and H_2^+ ions content in $^4He^{2+}$ beam is very low.

4. $^4He^{2+}$ AND H_2^+ ION BEAM SEPARATION WITH CARBON FOILS APPLICATION

Electron losses, electron captures (recharge, stripping, neutralization) and molecular ion dissociation processes are possible when ion passes through thin foils. Therefore, a thin carbon foil was installed in front of the beam-bending magnet. The main reason is H_2^+ dissociation to H^+ and H^0. But these particles will not be injected to beam line through mass analyzer and He ion beam will be purged from hydrogen ions wherein part of $^4He^{2+}$ ions could be lost.

Thin carbon foils of NSC KIPT production were used in $^4He^{2+}$ and H_2^+ ion beam separation experiments. These foils were produced by vacuum arc deposition. Thickness and their composition were analyzed by RBS technique. On Fig.3 $^4He^+$ RBS spectrum from thin carbon foil is shown. The foil consists of C (98% $at.$), O (1.9% $at.$), K (0.1% $at.$). Thickness equal $79\,nm$.

As it is known from literature references [7], an ion charge state distribution occurs when helium ion passes through thin carbon foils.

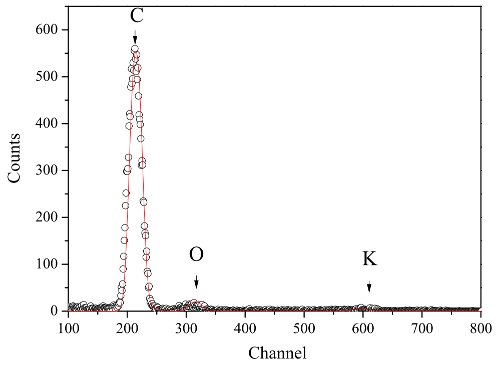

Fig.3. *1.8 MeV $^4He^+$ RBS spectrum from thin carbon foil, thickness – 79 nm, registration angle is 170°*

According to this data (Fig.4a), use of carbon foil with 79 nm (18 $\mu g/cm^2$) width in experiments with $^4He^{2+}$ beams energy from 2 to up 3.5 MeV the $^4He^{2+}$ beams losses by electron capture will be less then 5%.

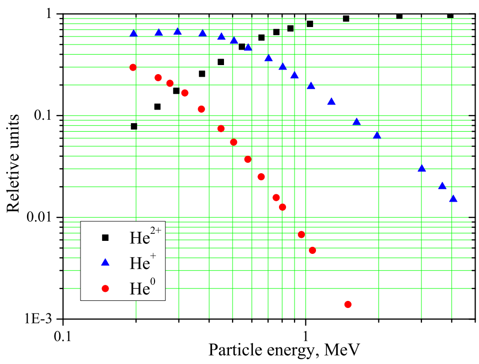

Fig.4a. *Charge spaces distribution of He after passing carbon foil with thickness 79 nm (18 $\mu g/cm^2$)*

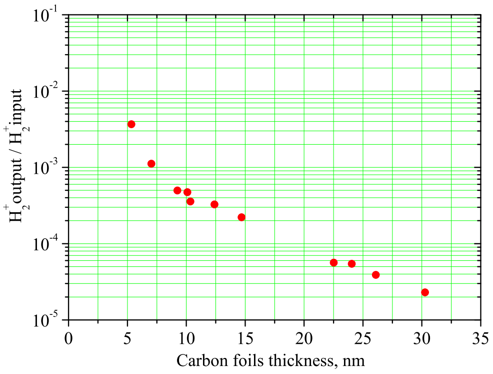

Fig.4b. *Ratio $H_2^+ output/H_2^+ input$ depends of carbon foils thickness, initial H_2^+ ions energy - 1.6 MeV*

When H_2^+ ions pass through carbon foils, as like shown in reference [8], H_2^+ molecular ion dissociation will be the main process at increasing of foil thickness. Dependence of $H_2^+ output/H_2^+ input$ relative yield from carbon foils thickness for 1.6 MeV H_2^+ ions is shown on Fig.4b.

The calculation of He beam with initial energy 3060 keV pass through such foil by $SRIM\,code$ [9] showed that energy loss of $^4He^{2+}$ beam will be equal to 14.5 keV, and straggling – 5.5 keV (Fig.5a). Similar calculation was done for carbon foil with width 300 nm that used in this experiment too. In this case, the ion energy loss is equal to 75 keV and straggling – 10 keV, when initial energy of He ions was equal to 3120 keV (Fig.5b).

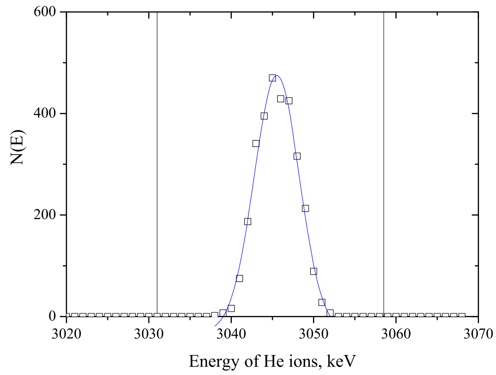

Fig.5a. *Energy distribution of 3060 keV He ions after passing 79 nm carbon foil*

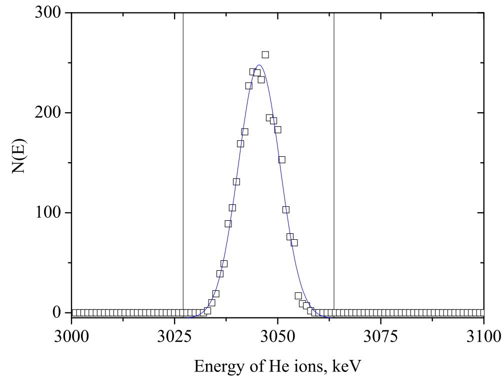

Fig.5b. *Energy distribution of 3120 keV He ions after passing 300 nm carbon foil*

Thus, use of 80 nm carbon foil in front of beam-bending magnet guarantees low losses of $^4He^{2+}$ ions and theoretically total dissociation of H_2^+ molecular ions.

For this separations experiments carbon foils device (10) was developed. This device was installed between accelerating tube and beam-bending magnet. The foils device can operate several foils (depends of their squares) and provides the foils movement in vacuum.

From He and H back scattering particles (Fig.6) yield ratio of Ta target (considering the cross-sections and stopping powers) ion currents ratio of $^4He^{2+}$ and H_2^+ were calculated. The results are for carbon foil with width of 300 nm ion currents ratio was equal to 88 and for carbon foil with width 79 nm this ratio is 52. Therefore, thin carbon foils application allows to obtain very low $^4He^{2+}$ and H_2^+ ion currents ratio.

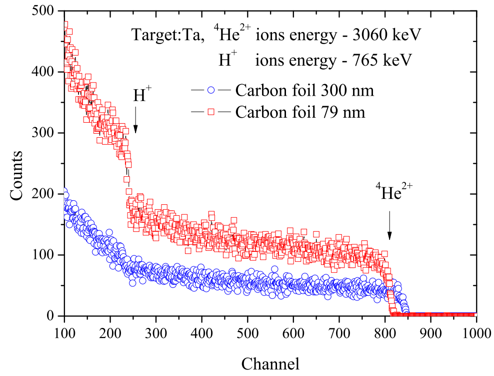

Fig.6. *RBS spectra from Ta target with* 300 *and* 79 *nm carbon foils application in separation experiments*

However it should be noted that application of carbon foil with thickness more than 100 nm for He ion energy range up to 3.6 MeV can result in ineligible effects that impair the analytical possibilities of IBA technique. These should include: $^4He^{2+}$ ion currents losses by electron capture, increasing of energy losses and straggling.

5. CONCLUSIONS

$^4He^{2+}$ and H_2^+ ion beams separation methods have been developed for "Sokol" IBA facility of NSC KIPT. In the first case, beam-bending magnet and electrostatic analyzer installed after it are used. In the second case, carbon foils for dissociation of H_2^+ ions. Foil holder was designed. Several foils could be installed in it, and they move under direct beam vacuum.

Both methods were tested. It is shown that both methods allow to obtain $^4He^{2+}$ beams with low composition of H_2^+ ions.

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РАЗДЕЛЕНИЕ ПУЧКОВ ИОНОВ $^4He^{2+}$ И H_2^+ НА АЯФК "СОКОЛ"

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На аналитическом ядерно-физическом комплексе "Сокол" ННЦ ХФТИ использовано два метода разделения пучков ионов $^4He^{2+}$ и H_2^+: с помощью существующего раздаточного магнита и электростатического анализатора; диссоциации ионов H_2^+ при прохождении пучка через углеродную пленку, установленную перед раздаточным магнитом. Показано, что эти методы позволяют существенно уменьшить содержание ионов H_2^+ в пучке $^4He^{2+}$.

РОЗДІЛЕННЯ ПУЧКІВ ІОНІВ $^4He^{2+}$ ТА H_2^+ НА АЯФК "СОКОЛ"

С. Г. Карпусь, О. В. Гончаров, В. М. Пістряк, А. В. Зац, В. В. Кузьменко, В. Н. Бондаренко, В. І. Сухоставець, Л. С. Глазунов

На аналітичному ядерно-фізичному комплексі "Сокол" ННЦ ХФТІ використано два методи розподілу пучків іонів $^4He^{2+}$ та H_2^+: за допомогою існуючого розподільного магніту та електростатичного аналізатора; дисоціації іонів H_2^+ при проходженні пучка через вуглецеву плівку, що була встановлена перед розподільним магнітом. Показано, що ці методи дозволяють суттєво зменшити вміст іонів H_2^+ у пучку $^4He^{2+}$.