MEASUREMENT OF THE ARGON IONS CURRENT ACCOMPAYNING AT THE ACCELERATING SOURCE OF EPITHERMAL NEUTRONS*

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Abstract

For the development of a promising method for the treatment of malignant tumors - boron neutron capture therapy - the accelerator-based epithermal neutrons source has been proposed and created in the Budker Institute of Nuclear Physics. Argon ions formed during stripping of a beam of negative hydrogen ions to protons are accelerated and, in parallel with the proton beam, are transported along the high-energy path of the facility. Depending on the relative number of argon ions, their effect can be from negligible to significant, requiring their suppression. In this work, the current of argon ions reaching the beam receiver in the horizontal channel of the setup was measured. It was determined that the argon beam current accompanying the proton beam is 2000 times less than the proton beam current. This makes it possible not to apply the proposed methods of its suppression.

INTRODUCTION

Charged particle accelerators are widely used in scientific research, medicine, and other applications. Tandem accelerators are high-voltage electrostatic accelerators in which the high-voltage potential is used twice: first to accelerate negative ions, and then, after changing the polarity of their charge in the high-voltage terminal, to accelerate positive ions. Thin foils are used for the conversion of the ion charge, or, at a higher ion current, gas stripping targets similar to the argon target in the tandem accelerator of the Budker Institute of Nuclear Physics of the Siberian Branch of the Russian Academy of Sciences. The stripping gas target provides effective stripping of the negative ion beam; however, its use leads to the formation of an undesirable beam of argon ions, which are formed in the stripping target as a result of argon ionization by the ion beam and penetrate into the accelerating channel. The aim of this work was to measure the current of an argon ion beam in a tandem accelerator with vacuum insulation.

THE EXPERIMENTAL SCHEME

The studies were carried out at the accelerator neutron source of the Budker Institute of Nuclear Physics (Novosibirsk, Russia). The source diagram is shown in Fig. 1 and its detailed description was given in [1]. A tandem accelerator with vacuum insulation was used to obtain a stationary proton beam with an energy of 0.6 to 2.3 MeV and a current of 0.3 to 10 mA, that is, a tandem accelerator of charged particles with an original design of electrodes. In it, unlike traditional accelerators, there are no accelerating tubes; the high-voltage electrode and electrodes with an intermediate potential are embedded in each other and fixed on a single feedthrough insulator, as shown in Fig. 1. This configuration of the accelerator made it possible to improve the high-voltage strength of the accelerating gaps and, as a consequence, to increase the proton current. One of the main elements of the tandem accelerator is the stripping target 4 placed inside the high-voltage terminal. It provides the conversion of negative hydrogen ions to protons with a high efficiency, usually at the level of 95%. The target is a 400-mm long cooled cylindrical copper tube with an inner hole diameter of 16 mm [1]. The interaction of a hydrogen ion beam with a gas target leads to its partial ionization, and a weakly ionized plasma is formed inside the stripping tube. Since electrons are more mobile than argon ions, the plasma assumes a positive potential to maintain quasineutrality.

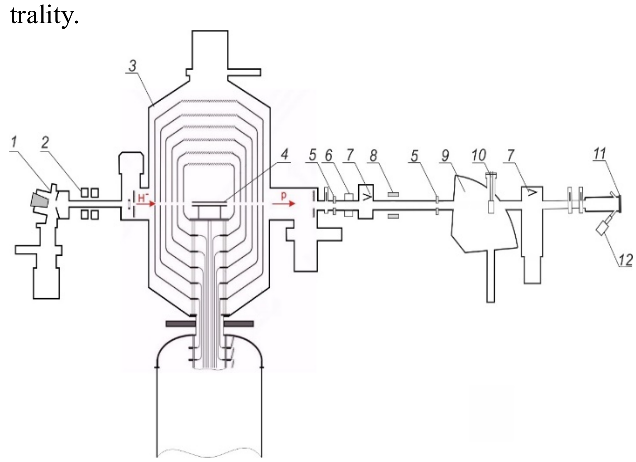

Figure 1: A diagram of an accelerator based source of epithermal neutrons. 1 - a source of negative hydrogen ions; 2 - magnetic lens, 3 - vacuum-insulated tandem accelerator; 4 - gas stripping target; 5 - cooled diaphragm; 6 - contactless current sensor Bergoz (France); 7 - Faraday cups; 8 - corrector; 9 - bending magnet; 10 - cooled beam receiver with a diaphragm; 11 - lithium target; 12 - Hikvision video camera (China).

Under the action of the positive potential, part of the argon ions leaves the stripping tube, enters the accelerating channel, and forms a beam of argon ions. Simple estimates of the argon ion current give values from commensurate to negligible in comparison with the proton

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current. It is difficult to reliably estimate the magnitude of the argon ion current due to the inhomogeneity of the converted beam and secondary plasma along the target, the possibility of the development of beam-plasma instability, the penetration of the electric field of the accelerating gaps into the high-voltage terminal, and many other parameters that are not reliably known. To suppress the penetration of argon ions into the accelerating gaps, it was proposed to place metal rings under a negative or positive potential in front of and after the stripping target, or to deflect the ion beam by a magnetic field inside the high-voltage terminal [2]. The formation of an argon ion beam was indicated by two experimental facts. First, the secondary ion current flowing along the periphery towards the accelerated beam of negative hydrogen ions was previously measured with a ring detector [3]. It is possible that argon ions escaping from the stripping target also contribute to this current. However, it is more likely that the main contribution to this current is made by the positive ions formed in the accelerator gaps as a result of the ionization of the residual or stripping gas by the hydrogen ion beam. In this case, positive ions are formed mainly in the first accelerating gap due to its length and high ionization cross section at a relatively low velocity of negative hydrogen ions. Second, when studying the radiation blistering of metals upon implantation of protons with an energy of 2 MeV [4], an earlier formation of blisters of a smaller than expected size from the implantation of protons was observed. This effect was explained by the presence of a beam of argon ions with an energy of 1 MeV; these penetrate the metal to a shallower depth than protons and can deform a metal surface faster with smaller blisters.

RESULTS AND DISCUSSION

The measurements were carried out at a proton beam current of 760 ± 10 μA, an energy of 1.850 ± 0.002 MeV, and a transverse beam size of approximately 1 cm.

The method of mass spectroscopy was used to measure the argon ion current. Inside the bending magnet 9 (see Fig. 1) a cooled diaphragm was inserted 10 with a 5 × 20 mm slot. Since the mass of an argon ion is 40 times greater than the mass of a proton and the kinetic energy is two times lower, the Larmor radius of an ion in a magnetic field is √20 times less than the Larmor radius of the proton and the bending magnet will deflect argon ions by an angle √20 times smaller than the angle of deflection of protons. The separation of the ion beam components is clearly visible on the surface of a lithium target, when the interaction of ions with lithium leads to luminescence recorded by a video camera 12 [5]. Figure 2 shows two examples of a video camera image: without a magnetic field and with a magnetic field. It can be seen that turning on the magnetic field divides the beam into three components: the flux of neutrals 1, the argon ion beam 2, and the proton beam 3.

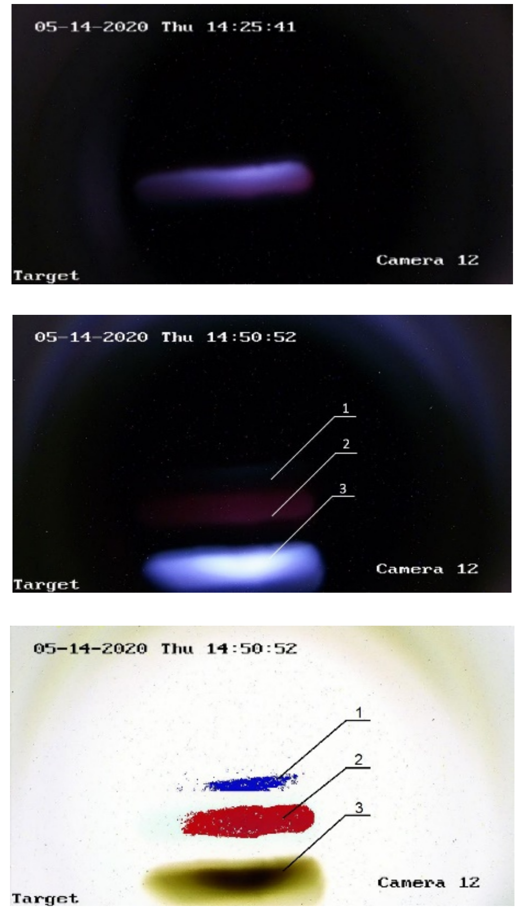

Figure 2: Images from a video camera looking at the surface of a lithium target at a bending magnet current of (a) 0 and (b) 14 A and (c) 14 A with partially inverted colors. 1, glow caused by neutrals (hydrogen atoms); 2, argon ions; 3, protons.

The scenario for measuring the argon ion current consisted in placing the diaphragm below the axis of the accelerator, directing the argon ion beam into the diaphragm opening with the magnetic field of the bending magnet, and deflecting the proton beam below. In fact, at a current of 68.5 A in the bending magnet coil, only a beam of argon ions passes through the diaphragm, which, upon hitting the lithium target, causes a characteristic luminescence recorded by a video camera. According to Fig. 3, at a current of 10 A in the bending magnet coil, an argon beam and a proton beam are visually visible on the surface of a lithium target, while at a current of 68.5 A, there is no proton beam; only beams of argon and neutral ions are visible.

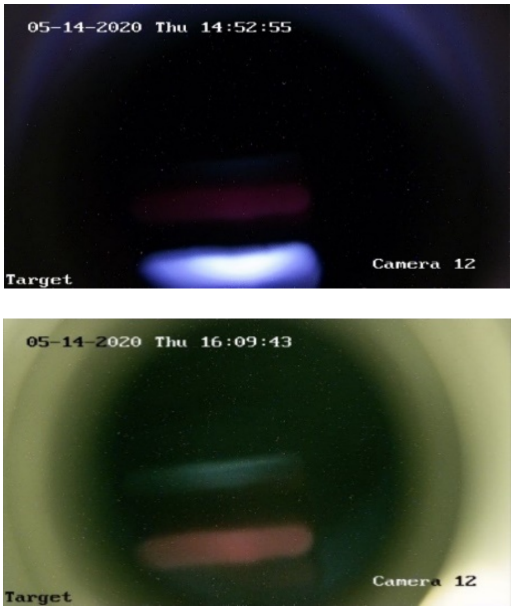

Figure 3: Images from a video camera looking at the surface of a lithium target: (a), with a current in the bending magnet coil of 10 A; (b), 68.5 A.

In this mode, at a current of 68.5 A, the current of charged particles passing through a hole in the diaphragm and hitting the surface of the lithium target was measured; it was 150 ± 70 nA. The current is measured by an ohmic voltage divider connected to the target unit (11 in Fig. 1), electrically isolated from the facility. Without the visualization of an argon ion beam by its luminescence on the surface of a lithium target, such a small value of the recorded current could be mistakenly considered as noise. The result we obtained was unexpected, since it was previously assumed that the current of argon ions is of course less than the current of protons, but not by very much. Since the maximum proton current that passed through the slit of the diaphragm is 286 ± 3 μA, then, assuming the sizes of the beams of argon ions and protons to be equal, we obtain that the current of argon ions is 2000 times less than the proton current. This result is the main result of this study. At such a value, the argon ion beam current does not pose a danger either as a source of additional heating of the lithium target, or as an additional load of a high-voltage power source, and therefore does not require means for its suppression. We will confirm the reliability of this result by an additional experiment and evaluation. For this purpose, we will double the frequency of opening the valve that supplies argon to the stripping target. A larger supply of stripping gas, as it should, leads to an increase in the argon ion current to 670 ± 150 nA and more intense luminescence, which can be seen from a comparison of the images in Figs. 3b and Fig. 4. As well, a larger gas supply leads to better stripping of the beam of negative hydrogen ions, which entails a decrease in the neutral flux, as can be seen from a comparison of the images in Figs. 3b and 4. We note that a two-fold increase in the supply of argon to the stripping target leads to an almost four-fold increase in the argon ion current, which is possible, since the outflow of ions from the stripping target depends on many processes and parameters. Even in this case, the argon ion beam current is very small compared to the proton current.

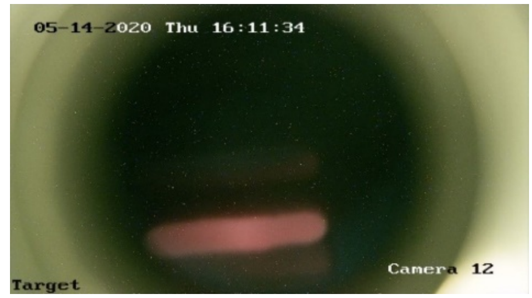

Figure 4: The argon beam glow and a beam of neutral atoms caused by the luminescence of the target lithium layer upon a twofold increase in the argon flow in the stripping target.

CONCLUSION

The Budker Institute of Nuclear Physics operates a vacuum insulated tandem accelerator, in which a gaseous argon stripping target is used to strip a beam of negative hydrogen ions into protons. The interaction of the ion beam with the stripping gas leads to partial ionization of argon, penetration of argon ions into the accelerating channel, and the formation of an accelerated beam of argon ions accompanying the proton beam. The magnitude of the argon ion beam current was measured by mass spectroscopy using a bending magnet and a cooled diaphragm; it is 2000 times smaller than the proton beam current. The reliability of the measurement is provided by visualization of an argon ion beam on the surface of a lithium target, as confirmed by an experiment with increased gas injection and an estimate of the possible contribution of the proton beam. Such a small value of the current of the argon ion beam poses no danger either as an additional heating of the lithium target or as an additional load of a high-voltage power supply and therefore does not require the previously proposed suppression means.

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