High Energy Physics and Nuclear Physics

Volume 19, Number 4

Experimental Results of the Off-Line Test Setup of Laser Ion Source

Xu Sida, Shang Rencheng, Zhang Shuming, Ye Zipiao, Zhang Wei, Zhao Zizheng[1], and Luo Yixiao[1]

(Physics Department, Tsinghua University, Beijing, China)
[1](Institute of Modern Physics, The Chinese Academy of Sciences, Lanzhou, China)

The off-line test setup of the laser ion source built in Tsinghua University is described briefly. The experimental result of laser resonant ionizing Na atoms carried by He gas at the outlet of He-jet are presented. The results indicate that the in-beam ionization of Na atom is viable. Based on these results, we can design a laser ion source that has high *Z* selectivity, high efficiency, low limits of lifetime for isotopes being studied, and is applicable for studying refractory elements.

Key words: ion source, He-jet, laser resonant ionization.

It is very important to enhance the sensitivity of the on-line isotope separator (ISOL) for the study of the nuclei far from β stability, and for the discovery and identification of new nuclei. The key point of the enhancement of the sensitivity is the reduction of the isobaric interference. The conventional ion sources are usually based on surface ionization or plasma produced by gas discharge. These kinds of ion sources usually have poor Z selectivity. Therefore, it very often happens that the counts from some interfering elements is a few orders of magnitude higher than that of the isotope to be studied, which makes the measurement impossible. For example, on the ISOL of the PS-BOOSTER at CERN, about 70 isotopes could be produced, only 30 of which are without serious interference [1]. Therefore, since the 1980s physicists have considered designing laser ion sources to overcome the difficulty. The Z selectivity could be realized by laser resonant ionization (LRI) in the laser ion source. The LRI can provide a Z selectivity larger than 10^{10}, better than 10^4 at worst. Because of the Z selectivity of the

---

Received on November 17, 1994. Supported by the National Natural Science Foundation of China.

laser ion source, the detecting sensitivity for low-yield isotopes could be enhanced by four orders of magnitude.

The laser ion source is usually related to the technique of He-jet. A certain pressure of He gas is pumped into the target chamber of nuclear reaction; the reaction recoils will be stopped in He gas, thermalized, and neutralized there. The atoms from the reaction recoils will be carried by He gas through a capillary to some point where the atoms will interact with laser beams to produce resonant ionization. The ions will be extracted by proper electrical field and injected into the ISOL. Three schemes of laser ion source were proposed in the last few years. The first scheme was proposed by V.S. Letokhov [2]. Radioactive nuclei were transferred to a hot cavity by Ha gas where the interesting atoms will be ionized by laser beam, extracted by certain electrical field, and injected into the ISOL. The second scheme was proposed by W.M. Fairbank and J.K.P. Lee [3,6]. The beams were extracted from He-jet or conventional ISOL containing radioactive nuclei and deposited on a film attached to a rotating wheel. When the wheel rotates to another position, a laser beam is focused on it to ablate the deposited radioactive nuclei, followed by several other laser beams to ionize the evaporated atoms resonantly. The third scheme was proposed by the authors' collaboration in 1989 [4]. A few laser beams were used to interact directly with the ion beams at the outlet of the He-jet, selecting the ionization of the atoms to be studied by resonant ionization. The ions were extracted and injected into the ISOL. Compared with the first two schemes, the third one possesses the following advantages:

1. High global efficiency: If high-repetition lasers are used, the ionization efficiency, which is defined as the ratio of the ion number of a certain element to the atomic number of the same element at the outlet of the He-jet, can be higher than 20%; combined with the high transport efficiency of the He-jet, a fairly high global efficiency (10^{-1} to 10^{-2}) could be obtained. The efficiency of the first proposal is also very high, the second one is fairly low ($\sim 10^{-4}$).
2. It is measurable for isotopes with short lifetime ($\sim$ms).
3. It is usable for refractory elements.

However, some disadvantages are also expected; for example, for enhancing the efficiency, high-repetition lasers (say, dye lasers pumped by cooper vapor laser-CVL) have to be used, which in general have narrower wavelength coverage than low-repetition lasers (say, dye lasers pumped by an exciter laser). Therefore, measurable elements would be limited.

In the middle of the 1980s, a group in Argonne tried to observe Ba atoms produced by nuclear reaction and Na atoms produced by damping the Na^+ beam from an accelerator in He gas, at the outlet of a He-jet by laser-induced fluorescence [5]. They failed to observe the fluorescence signals of Na and Ba atoms and were forced to suspend the experiment. Because of the failure of the Argonne group, in the last 10 years the method of direct ionization at the outlet of He-jet has been left out of consideration by physicists for the design of laser ion sources.

The Argonne group attributed their failure to the chemical reaction of interesting atoms with some contamination atoms in He gas (oxygen atoms played the major role). Besides, we conjecture there might be some other reasons, such as formation of clusters among different atoms in the supersonic jet, which may also result in the disappearance of monoatoms. Therefore, in our experiment, the following procedures were adopted: 1) adjusting the flow rate of He gas to prevent it from forming clusters, and 2) reducing the density of water vapor in the He pipe and vacuum system.

Before the study of on-line laser ion sources we constructed an off-line facility at Tsinghua University, Beijing. It includes a He-jet system, vacuum system, atomizer, ionization chamber, time of flight (TOF) mass spectrometer, electron beam generator, laser system, data acquisition, and automatic control system (see Fig. 1). The laser system consists of two dye lasers pumped by a frequency doubled YAG laser with an acoustic *Q* switch. The electron gun is mounted in the ionization chamber. The direction of electron beam is opposite to the He-jet. The electron ionization and laser ionization can be switched over from one to another very quickly. They can also be used together. The data acquisition system is based on a transit recorder F903 connected to a microcomputer.

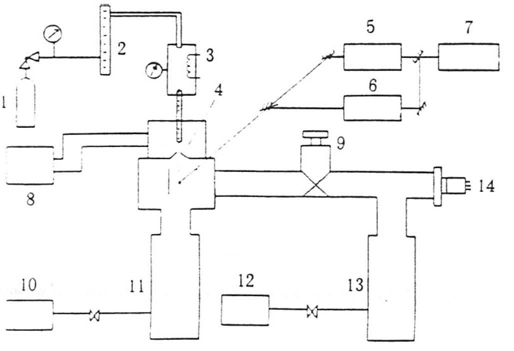

Fig. 1
The schema of the off-line test facility of laser ion souse built in Tsinghua University (THLITF).
1. He gas battle; 2. flowmeter; 3. atomizer; 4. skimmer; 5,6. dye lasers; 7. YAG laser; 8. mechanical pump (30 L/s); 9. valve; 10. mechanical pump (4 L/s); 11,13. molecular pump; 12. mechanical pump (8 L/s); 14. ion detector.

The installation of the system was finished in 1993. The static vacuum of the ionization chamber could reach 10^{-5} mm Hg, and 10^{-6} mm Hg in the TOF tube. Instead of a large pumping rate Rootz blower, we used a mechanical pump of 30 L/s. We studied the relationship of He flow rate and the vacuum pressure of different stages of the vacuum system systematically. If the flow rate of He is smaller than 10 mL/s, maintaining the vacuum is out of the question, which meets the experimental requirement. After the preceding study, the resolution of the system was calibrated by ionizing the residual gas and Hg vapor carried by He gas using electron ionization. For the isotopes of Hg, the mass resolution of 230 was obtained, which reaches the design goal.

In the last few months, we have studied the transport of Na vapor by He-jet and the ionization at the outlet of the jet. A small amount of metal Na was put into a graphite crucible in the atomizer,

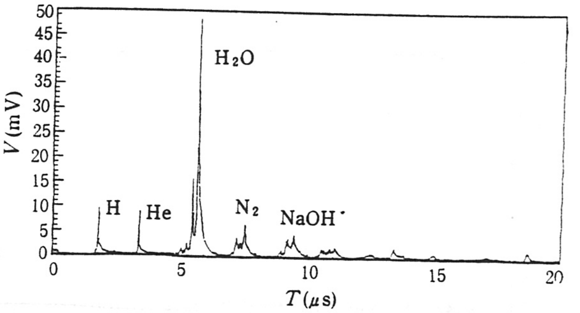

Fig. 2
When the density of water vapor is high, a very strong $(H_2O)^+$ peak could be observed on the TOF mass spectrum; a fairly strong peak at $m = 40$ appeared as well, which corresponds to the peak of $(NaOH)^+$.
V: amplitude; T: time of flight.

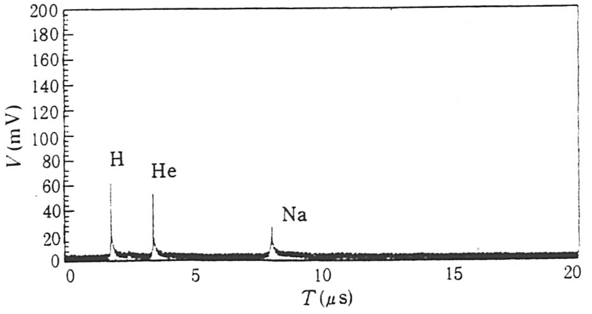

Fig. 3

After the density of water vapor was reduced, strong Na^+ peak was observed by electron beam ionization.

the Na was heated to evaporate, and the Na vapor was transported by He gas to the outlet of the He-jet; the transported distance was about 25 cm. In the first period of our experiment, no Na^+ signal was observed by electron ionization at the outlet. Instead, two phenomena were observed. First, the mass peak corresponding to (H_2O) was very high; second, a significant peak at $m = 40$ appeared (see Fig. 2), and its amplitude changed with the heating temperature of the Na metal. From the phenomena observed we can conclude that because of the high water vapor density, the atomic Na reacted with H_2O producing NaOH molecules, resulting in the disappearance of the Na signal and the enhancement of the peak at $m = 40$. We tried somehow to reduce the density of water vapor by almost an order of magnitude, and reduced the electron energy below the I.P. of most residual gas molecules but above that of Na atoms. A strong Na peak was then observed (see Fig. 3). The observation of Na signal by electron ionization implies that monoatoms of Na could be transported by He gas. The possibility of producing Na from the fragmentation of Na clusters or chemical compounds may not be excluded completely. Therefore, further experimentation on laser resonant ionization is necessary. Two laser beams of wavelength 589 nm and 616 nm from two dye lasers were used to pump Na atoms from the ground state to the 1st excited state (2*P* state) and from the 2*P* state to the 3*S* state, respectively. Both of the two beams could be used to ionize the atoms from 3*S* states. When the two beams both are tuned

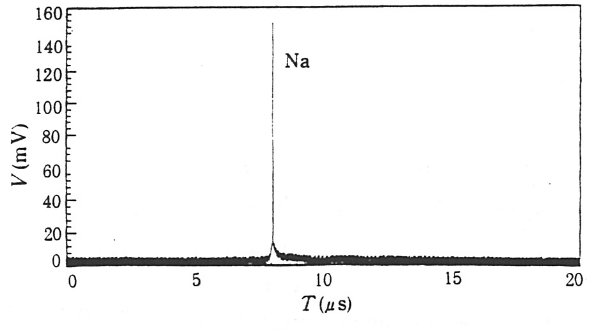

Fig. 4

The Na^+ peak observed via laser resonant ionization by two laser beams; the amplitude is more than an order of magnitude higher than an electron beam ionization.

to resonant wavelengths, a Na peak about 10 times stronger than electron ionization was observed (see Fig. 4). Even if both laser beams contribute to the ionization step, the summing energy per pulse is only 0.1 mJ, and the ionization probability is estimated to be about 0.1%. We can conjecture that the density of Na atoms at the outlet of the jet is very high. However, the quantitative calculation of the ionization efficiency and transporting efficiency cannot be done based on the present experiment. Quantitative study is under way.

Our experimental results proved that a He-jet system can effectively carry Na atoms thermalized in He gas. It also proved that resonant ionizing of the atoms to be studied right at the outlet of the He-jet is a simple and effective method. The scheme of laser ion source proposed by our collaboration is applicable. We are now studying the laser ion source for on-line use in the heavy ion accelerator in the Modern Physics Research Institute, The Academy of Sciences. The design and installation are under way.

REFERENCES

[1] J. Barker *et al.*, CERN/ISC 93-10 ISC/IP47.

[2] V.S. Letohhov, Proposal for ISOLDE-CERN, ZZNAL, 1984.

[3] J.K.P. Lee, *Nucl. Istr. Meth.*, **B26**(1987) p.444.

[4] Shang Ren Cheng, An invited talk to the Int. Symp. Heavy Ion Phys. and Appl., Oct. 1990, Lanzhou.

[5] C.N. Davids *et al.*, ANL85-22.

[6] W.M. Fairbank, Jr., *Nucl. Instr. Meth.*, **B26**(1987) p.357.