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GALS – setup for production and study of multi-nucleon transfer reaction products: present status

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Abstract. This is a brief report on the current status of the new GAs cell based Laser ionization Setup (GALS) at Flerov Laboratory for Nuclear Reactions (FLNR) - JINR, Dubna. GALS is planned to exploit available beams from the U-400M cyclotron in low energy multi-nucleon transfer reactions to study exotic neutron-rich nuclei located in the "north-east" region of nuclear map. Products from 4.5 to 9 MeV/nucleon heavy-ion collisions, such as ^{136}Xe on ^{208}Pb , are to be captured in a gas cell and selectively laser-ionized in a sextupole (quadrupole) ion guide extraction system.

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1. Introduction

The heavy neutron rich nuclei in the "north-east" part of the nuclide chart are from extremely importance for nuclear physics investigations, especially for the understanding of astrophysical nucleosynthesis and r-process. The closed neutron shell $N = 126$ —the so called last “waiting point” for the r-process—is located just in this region (figure 1). Neutron shell $N = 126$ is a classical shell closures for nuclei along the line of stability. However, as one moves away from the line of stability, abrupt changes in nuclear structure can arise. Especially, appearance of new magic numbers and/or disappearance of traditional ones as well as the onset of deformation are expected, as e.g. already observed in the region of lighter nuclei. Study of the structural properties of nuclei along the neutron shell $N = 126$ could contribute to the current discussion about the quenching of shell gaps in nuclei with large neutron excess. A creation and launch of this facility will open a new field of research in low-energy heavy-ion physics, and new horizons in the study of unexplored “north-east” area of the nuclear map. It could be helpful also for finding a new way for the production of heavy and superheavy nuclei.



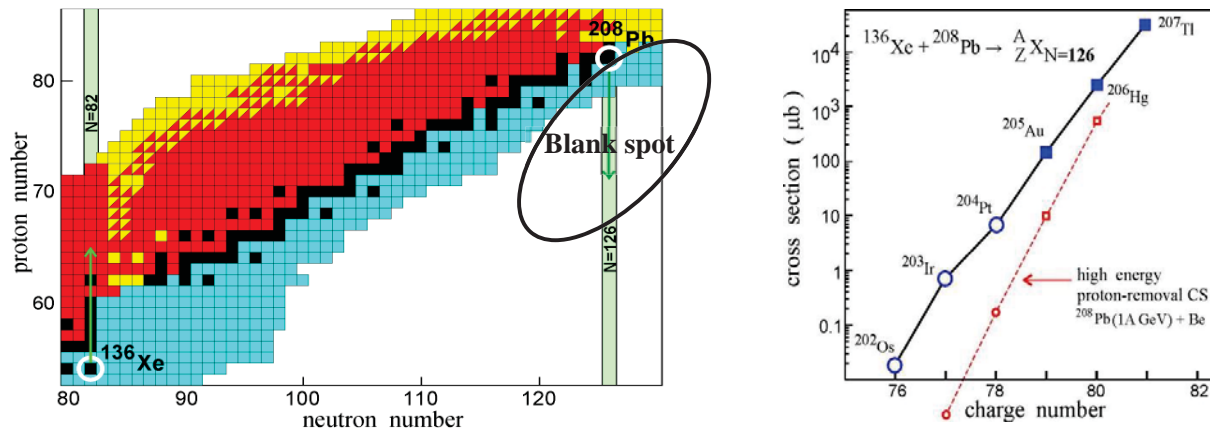


Figure 1. Left: upper “north-east” part of nuclear map. Right: cross sections for the formation of heavy nuclei in collisions of $^{198}\text{Pt} + ^{238}\text{U}$ at center-of-mass energy of 700 MeV. Open circles indicate unknown isotopes [1]. The dashed curve illustrates the yield of the same isotopes in the proton removal reaction from closed shell nucleus ^{208}Pb .

Experiments at GALS are intended for production of heavy neutron rich nuclei in the above mentioned region by using multi-nucleon transfer reactions. As shown by Zagrebaev and Greiner [1], several tens of new nuclides in the region of $N = 126$ and $Z \sim 75$ can be produced, for example, in the near-barrier collision of ^{136}Xe with ^{208}Pb . Even higher cross sections have been predicted for the production of new neutron rich nuclei in collisions of ^{198}Pt beam with ^{238}U target. At present this seems to be the only realistically method [1-3] that could fill the “blank spot” of the nuclear map (figure 1).

2. Experimental stage

A most suitable experimental method for the purpose of this project is a combined method of Z and A/Q separation. Such method has been proposed by Van Duppen *et al* [4] in 1992 and subsequently intensively studied (first at LISOL) and developed [5-13]. Known as In-Gas Laser Ionization and Spectroscopy (IGLIS), it is based on stopping of nuclear reaction products in a gas cell and subsequent selective resonance laser ionization [5-13]. Such technique allows extracting nuclei with a given atomic number Z , while a separation of the single-ionized isotopes by their mass number can be done rather easily by a magnetic field. Half-lives of heavy neutron rich nuclei of interest (as a rule, β -decaying), are much longer than the extraction time of ions from a gas cell.

2.1 Description on the experimental setup

The schematic layout of the proposed facility can be found in [2, 3]. Here we present only a brief description of the GALS facility (figure 2). Neutron rich isotopes of heavy elements are produced in multinucleon transfer reactions with heavy ions accelerated up to 5–10 MeV/nucleon (depending on projectile-target combination). The target is a foil of about $300 \mu\text{g}/\text{cm}^2$ thickness (or larger). It is placed at the window of the gas cell (or inside it). Nuclear reaction products recoiling out from the target as multi-charged ions are thermalized and neutralized by collisions with highly-purified argon or helium buffer gas. Then the atoms of interest (with a given Z) are ionized by means of two or three-step resonance laser irradiation and are extracted by the gas flow through the exit into the vacuum chamber as singly charged ions ($Q = +1$) with low energies of about 0.2 eV. Subsequently, the ions are confined in a radiofrequency

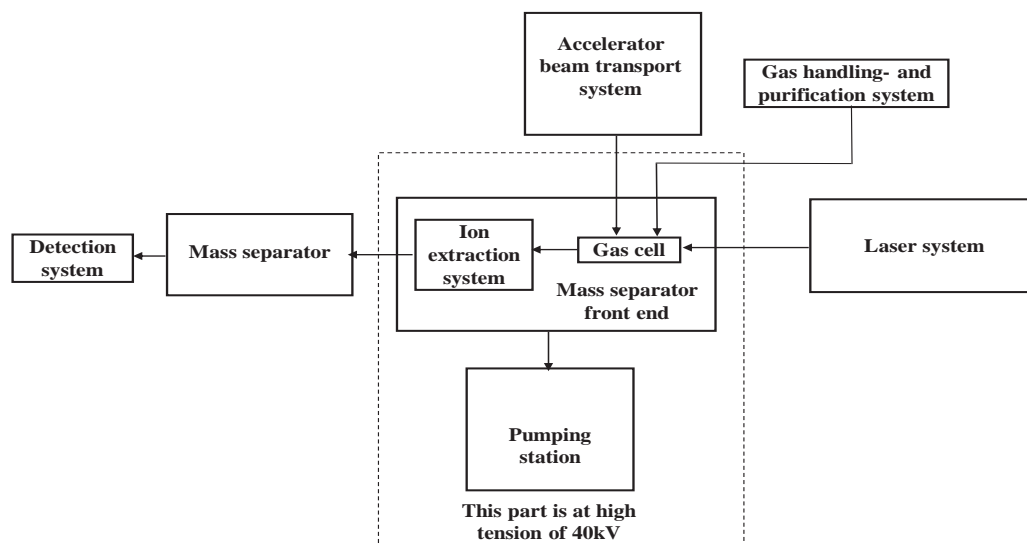


Figure 2. Block scheme of GALS-facilities.

ion guide system, which allows pumping out the residual buffer gas while transporting the ions towards the mass separator. Then the ions are accelerated up to 30–60 keV and selected by the mass–separator. In this way a low-energy beam of singly-ionized ions with a good optical quality (small emittance, energy spread less than 1 eV) is produced. This allows obtaining typical mass resolution of 1500 after the dipole magnet. After mass separation a beam of radioactive ions with a definite atomic number and a previously chosen mass value is obtained. The background due to unwanted isobar and isotope admixture is significantly suppressed that leads to an enhanced sensitivity. This gives the possibility to perform subsequently high sensitive analysis of spectroscopic and decay properties of these nuclei, as well as measurements of their spins, magnetic dipole and electric quadrupole moments and charge radii by means of laser spectroscopy. The operation principle of the different parts of the set up can be found in a number of papers (see e.g. [14] and the references therein). Below we sketch the plans of the GALS collaboration.

2.2 Present status

The GALS project will be realized in stage as determined by the FLNR plans and illustrated in table 1. The ion beams available at FLNR fully satisfy the requirements put from this project: the ions that can be used are quite different depending on the problem to be solved - from $^{16,18}\text{O}$ to ^{238}U , beam energies 4.5–9 MeV/nucleon (slightly above the Coulomb barrier) and beam intensity up to 10^{13} pps are accessible with a beam size at the target of 3–10 mm and beam emittance of $20 \cdot \pi \cdot \text{mm} \cdot \text{mrad}$. Different heavy targets, including those of actinides, are expected to be used. Therefore the new facility can be developed and coupled directly to the available U-400M accelerator.

The main parts of the facility to be created and their present status are shown in table 1. Mass separator could be a standard magnet separator similar to GPS at ISOLDE II (see [2, 15]) but nevertheless substantial efforts are needed for its realization. The same refers to the gas purification system. Both, separator and gas purification systems, are in stage of construction and their realization and commissioning will be delayed to the end of 2016. The experimental halls and laser system are in the most advanced stage of realization (see figure 3).

Table 1. Status of the project as well as the planned activities in the next two years.

		2015	2016	2017
Laser system	mounting	yes		Beginning of experiments
	commissioning	yes	yes	
Front end system	mounting	yes	yes	
	commissioning		yes	
Pump station	mounting	yes	yes	
	commissioning		yes	
	preparation	yes		
Gas purification	mounting		yes	
	commissioning		yes	
	preparation	yes		
Separator, detection	mounting	yes	yes	
	commissioning		yes	



Figure 3. Laser room with installed lasers.

Table 2. Laser to be used in multistep ionization. The lasers already delivered and installed are presented in bold.

Type	Output power main&harmonic, W (2 nd), {3 rd , 4 th }	Puls frequency, Hz	Puls length, ns	Wave length, nm
Dye laser	3, (0.3)	10⁴	10-30	213-850
Ti:Sapphir	2, (0.2), {0.04}	10 ⁴	30-50	680-960
Nd-YAG	(80-100), {20-40}	10⁴	10-50	532
Matisse system				
Ring dye	0.8-6	cw	cw	540-900
Ti:Sapphir	0.8-6.5	cw	cw	700-1000

The choice of specific laser ionization scheme, the type and number of lasers is determined by the ionization potentials and level schemes of the elements under study. In our case a three-step scheme of ionization looks more favorable. Such a scheme allows choosing more effective optical transitions to increase the yield of resonance-ionized ions, although the use of two-step ionization scheme is as not excluded as well. Dye laser systems pumped by second and third harmonics of Nd:YAG can provide tuning in a broad spectral range: from near UV to near IR [16]. The generation of a Ti:Sapphir lasers, shifted to the red and infrared edge of the spectrum (680-960 nm), can be also used as complementary to that of the dye lasers. Thus, the installation of two laser-ionization schemes—with dye lasers and Ti:Sapphir laser—would be of a great benefit allowing to meet diverse experimental demands. Such a double RILIS scheme is already realized in CERN [17]. The parameters of the delivered (and already installed) laser as well as of the ordered ones are summarized in table 2.

At the first stage of our experiments, excitation schemes using 3-step ionization with a non-resonant transition to continuum will be tested with the available lasers: two dye lasers Credo (Sirah) and Nd:YAG. Credo laser has maximal average power of 20 W at fundamental wavelength and 2 W at the second harmonics; its line width is 1.8 GHz at pulse duration about 7 ns. It is an option that allows remote control of wavelength with stabilization to an external laser wavelength meter. The Nd:YAG laser (product of Edge Wave GmbH) generates maximal average power of 90 W and 36 W for the second and third harmonic respectively with repetition rate 10 - 15 kHz and pulse duration of 8 - 10 ns. The divergence parameter of the green beam is $M^2 = 1.4$. It needs electrical power supply of 3.6 kW including 1.6 kW for the water chiller.

A Matisse series of a ring cw-dye laser and cw-Ti:Sapphir laser pumped by cw-Nd:YAG is planned as a seeding system. Such system has an advantage in the cases when tuning of the laser wavelength is necessary, e.g. for laser spectroscopy.

3. Outlook

A new GALS facility at FLNR cyclotron U-400M is in a stage of build-up. GALS will apply the highly selective and efficient technique of stepwise resonant ionization in a gas cell (of the element of interest) with subsequently mass separation. In fact, it is a mass separator from a new type as yet not used in JINR. GALS is addressed to the production and study of new neutron rich nuclei located along the neutron shell $N = 126$. This is the so called “north-east” part of the nuclear map. Nuclei from this region are as yet “terra incognita” but from high fundamental interest mainly due to their large impact of on the astrophysical r-process. The most efficient method to produce such nuclei, as motivated in [1], are the multi-nucleon transfer reactions.

The experimental method is rather universal and allows extracting besides heavy products of multi-nucleon transfer reactions also any other nuclei with half-lives longer than a few tens of milliseconds including neutron rich fission fragments, fusion reaction products and light exotic nuclei. Such studies are already performed at other facilities, for example, in Finland [9], Belgium [10-13], and also using a different approach as that of the hot cavity ion source at CERN [16-17]. The efficiency of such facilities varies from 1% to several tens percent depending on the half-life or the extracted ion

According to the estimation of the ion yields, at target thickness 0.3 mg/cm^2 , ion beam of 0.1 pmA and setup efficiency of 10% we would be able to measure decay properties of 1 new isotope per day.

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