IRiS 10

1st Workshop on
Inelastic Reaction Isotope Separator for Heavy Elements
March 01, 2010, GSI, Darmstadt, Germany

Program & Abstracts

TIME	TOPIC	Speaker	Page
09:00	**Welcome**	K. Langanke (GSI)	
	Introduction, Idea, General Scope	Ch.E. Düllmann (GSI)	
	Structure of the workshop	J. Dvorak (HIM)	
	Physics case / theory	**Chair: tba**	
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10:30	**Coffee Break**		
	Status: Relevant Experiments	**Chair:**	
10:50	Multi-nucleon transfer basics	J.V. Kratz (Univ. Mainz)	3
11:10	Actinide production in ^{238}U + ^{238}U (^{248}Cm) multinucleon transfer reactions revisited	M. Schädel (GSI)	4
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12:10	**Photo**		
12:30	**Lunch Break**		
	Existing Transfer Product Separators	**Chair:**	
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14:35	A Large Acceptance Spectrometer for Deep-Inelastic Scattering with re-accelerated Radioactive Beams **talk cancelled - printed version available**	G. Souliotis (Univ. Athens)	7
14:55	The HELIOS spectrometer at Argonne	B. Back (Argonne)	8
15:15	Spectrometers TWINSOL, BIGSOL	F. Becchetti (Univ. Michigan)	8
15:35	**Coffee Break**		
16:00	**Panel Discussion:** *Concepts for a dedicated heavy element multi-nucleon transfer product separator* • Scientific motivation • Wanted products and choice of reactions • Most promising designs • Solenoid x dipole, vacuum x gas-filled, superconducting magnets? • Collection & Detection: Buffer gas cell, RTC + gas-jet/chemistry, Si detectors + TOF, Mass measurements • Next steps		
17:50	**Concluding remarks**		
18:00	**End**		
19:00	**Dinner at "Weißer Schwan"(optional)**		

The r-process process production of heavy elements

G. Martinez-Pinedo

GSI Helmholtzzentrum für Schwerionenforschung mbH, Darmstadt

The astrophysical r-process is responsible for the production of half of the isotopes heavier than Iron including Uranium, Thorium and maybe superheavy elements. Our current understanding of r-process nucleosynthesis is limited by two factors. Firstly, we do not yet know the astrophysical site where the r-process occurs. Secondly, during the r-process very exotic nuclei are produced whose properties and decay modes are currently not known. Observations of metal-poor stars show evidence that the r-process has been acting already at the very early phases of Galactic evolution and producing always a very robust pattern for elements with charge number Z>56. In order to understand the origin of these robustness and the synthesis of elements like Uranium and Thorium, it is important to understand the evolution with neutron excess of the properties and decay modes of neutron-rich actinides.

Second wind in study of heavy ion damped collisions

V. Zagrebaev

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Recently we developed a dynamical model which allows one to describe properly and simultaneously all significant (and strongly overlapped) reaction channels in low-energy collisions of heavy ions, namely, deep inelastic scattering, quasi-fission and fusion-fission processes. Simultaneous consideration of all the reaction channels, a kind of unitarity, prevents from big deviations in absolute normalization of the corresponding cross sections. Good agreement of the model with available experimental data on the angular, energy, mass and charge distributions of reactions fragments, formed in deep-inelastic scattering and quasi-fission processes of heavy ion collisions, gives us confidence in receiving rather reliable estimations of the reaction cross sections for the production of neutron-rich supereavy nuclei and unknown isotopes located along the closed neutron shell N=126 – two regions of the nuclear map which attract so much attention last time. In my talk I will discuss our latest findings in this field.

Neutron Rich Nuclei via Multinucleon Transfer Reactions

G. Pollarolo

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and
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In this contribution I will discuss multinucleon transfer reactions between heavy nuclei as a tool for the production of heavy neutron rich nuclei. I will do this by analysing multinucleon transfer reactions with a semi-classical model that allows the identification of the important degrees of freedom that govern the exchange of mass and charge among the two reactants.

Multi-nucleon transfer basics

J.V. Kratz

Institut für Kernchemie, University of Mainz, Germany

Some basic features of damped binary heavy-ion collisions will be revisited. Wilczynski diagrams are presented for some representative target-projectile combinations and their scaling with the reduced Sommerfeld parameter. For ^{86}Kr + ^{166}Er, typical spectra such as $d\sigma/dE$, $d\sigma/d\theta$, and $d\sigma/dZ$ are presented. The question is discussed whether the scattering angle is a good measure of the interaction time or whether the charge variance σ^2_Z(TKEL) is a better clock. The one-body dissipation is introduced along with the recoil formula with its nuclear structure modification. The role of the potential energy surface for the evolution of the product distribution is presented together with some remarks on N/Z equilibration. The solutions of the Fokker-Planck equation are introduced and their applications to reproduce experimental data are presented. Charge variances measured at barrier energies are so large that they cannot be explained by the nucleon exchange model. The sharing of excitation energies exhibiting an extreme donor-acceptor asymmetry hints here to the mechanism of random neck rupture.

Actinide production in ^{238}U + ^{238}U (^{248}Cm) multinucleon transfer reactions revisited

M. Schädel

GSI Helmholtzzentrum für Schwerionenforschung mbH, Darmstadt

The nuclear reactions ^{238}U + ^{238}U and ^{238}U + ^{248}Cm were investigated at GSI in the late 70's. Radiochemical techniques were applied to obtain a complete picture about (i) the strength of different nuclear reaction channels, (i) isotope distributions and (iii) the production of heavy actinide isotopes in multinucleon transfer reactions [1-3]. Theoretical estimates for the production of these isotopes [4] allowed a deeper insight into the excitation energy distribution of the primary fragments and the mechanism for product formation. These data will be presented and perspectives and limitations for the production of unknown neutron-rich isotopes of heavy actinides and transactinides in U-induced reactions will be discussed.

[1] M. Schädel et al., Phys. Rev. Lett. **41** (1978) 469.
[2] M. Schädel, "Radiochemische Messungen der Bildungsquerschnitte von Aktinidenisotopen in der Reaktion von ^{238}U-Ionen mit ^{238}U", doctoral thesis, Johannes Gutenberg-Universität Mainz, 1979, and GSI-Report 79-8, 1979.
[3] M. Schädel et al., Phys. Rev. Lett. **48** (1982) 852.
[4] C. Riedel, W. Nörenberg, Z. Phys. A **290** (1979) 385.

Synthesis of below-target, neutron-rich nuclides in ^{136}Xe induced reactions

M. Schädel

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Extensive radiochemical studies of the Xe on Au reaction allowed for a better understanding of Xe induced quasielastic and inelastic reactions [1]. Similar investigations were carried out with U-targets [2] and with the emphasis on the production of heavy actinide nuclides with targets of U [3,4], Pu [4] ^{248}Cm [5], and ^{249}Cf [6]. It was found that ^{136}Xe is less advantages than other projectiles for the synthesis of "above-target" (higher-Z) nuclides. However, for the production of "below-target", neutron-rich nuclides in multinucleon transfer reactions ^{136}Xe seems to be the (or one of the) best choice(-s) to obtain maximum cross sections. This was exploited, e.g., in the reaction ^{136}Xe + ^{244}Pu which led to the discovery of the new nuclides ^{243}Np and ^{244}Np [7].

[1] J.V. Kratz et al., Phys. Rev. Lett. **39** (1977) 984, J.V. Kratz et al., Nucl. Phys. **A 332** (1979) 447, and J.V. Kratz et al., Nucl. Phys. **A 357** (1981) 437.
[2] R.J. Otto et al, Phys. Rev. Lett. **36** (1976) 135.
[3] M. Schädel et al., Phys. Rev. Lett. **41** (1978) 469.
[4] A. Türler, Lizentiatsarbeit, Universität Bern, 1985
[5] K.J. Moody, Ph. D. Thesis, Berkeley, 1983, Report LBL-16249 (1983)
[6] K.E. Gregorich et al., Phys. Rev. C 35 (1987) 2117.
[7] K.J. Moody et al., Z. Phys. A- Atomic Nuclei **328** (1987) 417.

Nucleon transfer reactions induced by A < 50 projectiles

A. Türler

Paul Scherrer Institut and Bern University

About 20 years ago, nucleon transfer reactions of A < 50 projectiles on actinide targets have intensively been studied. A rather complete set of nucleon transfer reaction cross sections was obtained using radiochemical methods for the reactions ^{40,44,48}Ca + ^{248}Cm [1-3]. Today we know that element 116 nuclides can be synthesized with several picobarn production cross section in the reaction ^{48}Ca + ^{248}Cm [4]. At the time, the observed nucleon transfer cross sections were compared with calculations of potential energy surfaces (PES), reflecting mainly changes in the Q-value of initial reactants and final products. These calculations and the observed nucleon transfer reaction cross sections suggest that above target products are mainly formed in quasi-elastic reactions and that the location of the maximum of the isotopic distribution is governed by the underlying PES. Below-target yields suggest that these nuclides are formed in deeply-inelastic and quasi-fission reactions. For neutron-deficient projectiles, the PES predict rather high excitation energies of primary products in excess of 20 MeV which probably leads to significant losses due to prompt fission. For above-target, as well as below-target elemental yields, the neutron number of the projectile had a significant influence and resulted in differences of one or more orders of magnitude!

[1] H.W. Gäggeler et al., PHYSICAL REVIEW C, 33 (6): 1983 (1986).
[2] D.C. Hoffman et al. PHYSICAL REVIEW C, 31 (5): 1763 (1985).
[3] A. Türler et al., PHYSICAL REVIEW C, 46 (4): 1364 (1992).
[4] Yu.Ts. Oganessian et al., PHYSICAL REVIEW C, 63 (1), 011301 (2001).

The gas-filled recoil separator RITU, an Inelastic Reaction Isotope Separator?

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RITU and Gamma groups

Department of Physics, University of Jyväskylä, Finland

A test experiment using ^{65}Cu beam on ^{209}Bi target at the Interaction Barrier energy employing the JUROGAM+RITU+GREAT array has been performed. The gas-filled recoil separator RITU was tuned to transport the target-like deep-inelastic products to the focal plane. The GREAT spectrometer was used for further identification using the α decay or the isomeric-γ decay as a tag. The Recoil-Decay-Tagging method (RDT) was employed to obtain γ rays originating from the neutron-rich projectile-like nuclei. The needed Doppler corrections were made using simple kinematics. In this test, for the first time, it was demonstrated that the RDT method can be applied to obtain γ rays originating from the neutron-rich projectile-like isotopes using the decays originating form the target-like heavy projectiles formed in deep-inelastic processes. The method, and some ideas how to improve it, will be presented. In addition, some observations about the reaction dynamics will be discussed.

VAMOS
Spectrometer for Binary Reaction Products

M. Rejmund

GANIL

Main features, operating modes and detection systems of the GANIL large acceptance magnetic spectrometer VAMOS will be presented. The identification techniques and applications for the binary reaction products issued from the heavy ion reactions at energies around the Coulomb barrier will be discussed and exemplified based on the recent results with

- deep inelastic multinucleon transfer reactions
- induced fission reactions.

The ongoing and future improvements will also be summarized.

A new gas-filled mode for the large-acceptance spectrometer VAMOS

C. Schmitt

GANIL

The magnetic spectrometer VAMOS of GANIL, characterized by a very large acceptance and a variable angle around the target, was so far operated under vacuum. The present contribution reports on the results of the test-experiment demonstrating the feasibility of a gas-filled operation of VAMOS. A detailed study of the performance of the new mode in terms of beam rejection, transmission and background suppression, as well as future plans are presented. The relevance of a flexible spectrometer, able to work in vacuum and in gas over a wide angular range, will be discussed in the context of multi-nucleon transfer reactions.

The PRISMA spectrometer : what we learned so far

L. Corradi

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With the advent of large solid angle magnetic spectrometers new possibilities are offered for different kind of studies in low energy heavy ion reactions. The PRISMA spectrometer has been extensively used in the last years to perform measurements on multinucleon transfer reactions, in stand alone and coupled to the gamma array CLARA. In this talk I will discuss a selection of results obtained in different reactions, showing the performance of the spectrometer in connection with possible new experiments to be done next.

A Large Acceptance Spectrometer for Deep-Inelastic Scattering with re-accelerated Radioactive Beams

G.A. Souliotis

University of Athens (Greece) and Texas A&M University (USA)

A large acceptance ray-tracing spectrometer has been designed in order to fully exploit the research opportunities that will be offered by reaccelerated radioactive beams in the energy range 6-15MeV/nucleon from the proposed Facility for Rare Isotope Beams (FRIB) in the USA and other similar facilities. The preliminary design of the spectrometer has been benefitted by several similar instruments in Europe (e.g. VAMOS, PRISMA, MAGNEX). The design is of QQD type (quadrupole-quadrupole-dipole) with two large-bore quadrupoles and a large-gap 70° bending magnet offering an angular acceptancearound 50 msr and a momentum acceptance of 10%. The focal plane dimensions are 60cm X 20cm and can accommodate two X-Y position sensitive detectors, a multi-segmented ionization chamber and a Si detector wall. The maximum magnetic ridigity is 2.5 Tesla-meter, providing a range appropriate for the most neutron-rich products expected from binary reactions with reaccelerated radioactive beams.

The spectrometer will be mounted on a platform allowing rotation around the target in a wide angular range. It is envisioned that the spectrometer will play an important role in the rich research directions in nuclear structure and reaction studies, combined with gamma-ray and particle arrays around the target.

The HELIOS spectrometer at Argonne

B. B. Back

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The availability of exotic beams at the ATLAS facility at Argonne and elsewhere opens the possibility of detailed studies of the single-particle aspects of nuclear structure in neutron-rich nuclei reaching out to the astrophysical r-process path by employing light-ion reactions in inverse kinematics. HELIOS is a new spectrometer that is especially well suited for such studies. It circumvents the problem of kinematical compression of the excitation spectra at backward angles by transporting charged particles along helical trajectories in a strong, axial magnetic field. By measuring the longitudinal position, energy, and time of arrival when the particle returns to the beam axis one obtains a full kinematical characterization of two-body reactions and particle identification for light particles. By measuring the longitudinal position, instead of the emission angle, the energy dispersion is identical to that of the centerof- mass system. This leads to a Q-value resolution that is up to three times better than what can be obtained by conventional systems. I will discuss the salient properties of this concept and present some preliminary results from the first HELIOS experiments. The combination of neutron-rich beams from the new CARIBU injector at ATLAS and the HELIOS spectrometer opens a fertile research area of precision studies of these exotic nuclei.

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Spectrometers TWINSOL, BIGSOL

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The University of Michigan nuclear group along with collaborators at various U.S. H.I. research facilities (MSU-NSCL,ANL,UND,TAMU) have designed and operated a number of large-bore, high-field superconducting solenoid –based systems (single and dual magnet) for use as multi-particle spectrometers, and more generally as RNB production devices (see e.g. http://research.physics.lsa.umich.edu/twinsol). The characteristics along with advantages and limitations of such devices used in these various modes of operation will be discussed along with some potentially useful new configurations one might consider (with radial E lenses, gas-filled mode, etc.).