EINGEGANGEN 20. Nov. 2000

Date of Receipt: ____________ GSI Exp. No. E049 ~~S257~~

Proposal for an Experiment at GSI, Darmstadt

1. Title of Proposal: In the Study of Beta Decay in Highly Charged Ions

☑ New Proposal ☐ Continuation of Previous Experiment (Exp. No.:.........................)

2. Spokesperson:

Spokesperson:	Full Address:	Telephone/Fax:	email:
F. Attallah	GSI	2743	F.Attallah@gsi.de
F. Bosch	"	2713	F.Bosch@gsi.de

3. Participants: Address: Telephone: email:

(see attachement).

4. GSI Contact Person: F. Attallah, F. Bosch

5. UNILAC: ☑ SIS: ☑ ESR: ☑

6. Requested Beam Properties and Experimental Equipment:

a) Ion Species (Charge State if Needed): ^{174}Yb
b) Intensity (Particle nA): max
c) Energy (MeV/u): 800
d) Target Station: ^{9}Be
e) Special Requests on Beam Properties: ✓
f) Special Target Requirements: ✓
g) Electronic Pool: ✓
h) GSI Computers: Yes
i) Safety Requirements: ✓
j) Further Assistance Requested from GSI: ____________

7. Requested Beam Time (in Shifts of 8 Hours each)

Total: 21 Number of Runs: 1

Prefered Dates: ____________ Dates when you cannot run: ____________

8. Detailed description of the Proposal: Please attach an experiment description (max. 10 pages including figures) which should summarize the scientific justification and relevant technical details for the proposed experiment. For a continuation request, a brief status report of the previous as well as an outline of the future experiments should be given.

Date: (Do not fill in) GSI Exp.No.:

SUPPLEMENTARY FORM FOR SAFETY ASPECTS OF A PROPOSAL

Title: In The Study of Beta Decay in Highly Charged Ions

Spokesperson: F. Attallah, F. Bosch GSI-Contact Person:

1. General Safety
   a. Do you use combustible or hazardous gases within your experiment (e.g. gas target, gas detectors)? Yes ☐ No ☑
      What sort of gases?
      Which quantities or flow rates?
   b. Do you use other dangerous (e.g. toxic, inflammable, biologically hazardous etc.) materials within your experiment? Yes ☐ No ☑
      What sort of materials?
      Which quantities?
   c. Is your vacuum set-up equipped with fragile parts like thin glass or foil windows etc. (danger of implosion)? Yes ☐ No ☑
      Brief description of the construction:
   d. Is it intended to move heavy parts for setting-up your experiment or during the experiment? Yes ☐ No ☑
      Brief description of the equipment and working procedure:
2. Radiation Safety
   a. Do you use radioactive sources or materials on-site? Yes ☐ No ☑
      What sources?
      Which activities?
   b. Is it intended to direct the beam through air or other gases? Yes ☐ No ☑
      Beam sort, energy, intensity:
      Distance through air or gas:
3. Electrical/Laser Safety
   a. Do you use electrical instruments on-site? Yes ☐ No ☑
      Max. Voltage/max. current:
   b. Do you use high-intensity radio frequency (RF) sources on-site? Yes ☐ No ☑
      Frequency region/power:
   c. Do you use lasers in your experiment? Yes ☐ No ☑
      Laser-type, max. power:
4. Is there any other special safety aspect to be considered in connection with your proposal? Yes ☐ No ☑

Date: 10·11·2000

Spokesperson of the experiment: F. Attallah

In The Study of Beta Decay in Highly Charged Ions

F. Attallah [a] P. Beller [a], K. Beckert [a], F. Bosch [a], D. Cortina [b],
H. Geissel [a], B. Franzke [a], F. Hammache [a], M. Hausmann [a],
M. Hellström [a], J. Kiener [c], O. Klepper [a], C. Kozhuharov [a],
A. Lefebvre [c], D. Lunney [c], G. Münzenberg [a], Y.N. Novikov [d],
F. Nolden [a], T. Ohtsubo [a], W. Quint [a], T. Radon [a], H. Schatz [e],
C. Scheidenberger [a], K. Schmidt [f], M. Steck [a], T. Stöhlker [a],
K. Sümmerer [a] H. Weick [a], M. Winkler [g]

[a] *GSI, Planckstr 1, D-64291 Darmstadt, Germany*
[b] *Dep. of Physics, Univ. of Santiago, Spain*
[c] *CSNSM, IN2P3-CNRS, F-91405 Orsay, France*
[d] *St. Petersburg Nuclear Physics Institute, 188350 Gatchina, Russia*
[e] *NSCL, MSU, East Lansing, MI 48824-1321, USA*
[f] *Dep. of Physics and Astronomy, Univ. of Edinburgh, Edinburgh EH9 3JZ, UK*
[g] *II. Phys. Inst., JLU Gießen, Heinrich-Buff-Ring 16, D-35392 Gießen, Germany*

Spokespersons : F. Attallah, F. Bosch

1 Introduction

β decay plays an important role at various stages of the stellar evolution and in many nucleosynthesis processes, as the high energy β^- decay of very-neutron-rich nuclei synthesized by the r-process (1), and the β^- transition between low-lying levels of heavy nuclei under less explosive stellar conditions such as are realized in the s-process (1). The results or the methods themselves of the theoretical calculations of such process rates are still in controversy mainly because of our lack of precise knowledge about β-strength functions. Such knowledge for neutron deficient heavy nuclei will also be requested in studies of the rp-process. In other words, a global knowledge of the β-strength distribution over a wide range of energies is primarily required but not yet achieved up to now neither theoretically nor experimentally. Moreover, because of the high temperature that almost completely strip off the nuclei new decay modes arise as the *Bound* β decay (2) ($b\beta$), a β^- decay where the ejected electron ends up in an atomic bound state instead of the continuum as is the case in the usual β^- decay ($c\beta$). The two decay modes do coexist all the time such that the probability of β^- decay should be reformulated as the sum of these 2 branches $\lambda_\beta = \lambda_{c\beta} + \lambda_{b\beta}$. Next to the energy dependence, the branching ratio ($\lambda_{b\beta}/\lambda_{c\beta}$) depends also on the charge state, and varies from 0 in neutral atom up to many orders of magnitude in the bare ion (3; 4). This induces a dramatic change in the lifetime of the isotopes of concern as was observed in the case of ^{163}Dy (5) and the cosmochronometer ^{187}Re (6).

In the β^+ decay rate, besides the enhancement due to the Q-value increase, the effect of the disappearance of the total electron screening was estimated (7; 4) to some percent only due to the weak part of the screening induced inside the nucleus. Experimentally the behaviour of the β^+ decay versus the charge state dependence is also questionable as far as the electrons close to the nucleus may have indirect implication in this process (8). The electron capture (EC), however, simultaneously depends on the number of electrons in the vicinity of the nucleus and of the electronic wavefunction at the nucleus. These 2 parameters evolve in different and opposite way, and the charge state dependence of the EC decay rate as well as the branching ratio EC/ β^+ , lack data.

In all the experimental systems studied so far only bare ions or quasi/neutral atoms were used. However, e.g. in the stellar media like under plausible s-process conditions, the ionization of the heavy atoms concerned is expected to be incomplete. This necessitates, at least in the studies of β-transition at low energies, a detailed treatment of various ionic states. Indeed, a few theoretical attempts have been made in this direction but their results are either highly questionable (9) or not verified experimentally (4). Moreover a new phenomenon may rise in the H-like systems where one can expect a coupling between the electron spin and the nucleus spin as was already seen in the case of internal conversion (see e.g. (10)). This would change significantly the lifetime and would lead to new selection rules.

2 Experiment

We propose to study the β-decay (β^- , bound β^- , β^+ , EC) to evaluate the [illegible] strength parameters as well as the charge state dependence of the branching ratios in [illegible] e case of bare, H-like, He-like, and Li-like ions while measuring the nuclear lifetimes. [illegible] Li-like ions, the decay rate is very close to the rate in the neutral atom, and [illegible] be used to recalibrate the systems. These measurements will be performed in [illegible] using Schottky spectroscopy with electron cooled ions (11). The isotopes of [illegible] will be produced by projectile fragmentation, in-flight separated by the FRS and [illegible] into the ESR. The projectile fragmentation cross section of a mbarn magnitude [illegible] otope production to 10^6 ions/spill, which will restrict these studies to [illegible] ne days and bellow to the minute range.

[illegible] transition should be investigated within these charge states to establish [illegible] ur of β-decay versus the atomic charge state. The transition [illegible] ical parameter, but for this pilot experiment we would like to [illegible] ^{70}Tm for β^-decay and ^{136}La for β^+decay.

[illegible] ongly enough to overwhelm the n-capture branch, [illegible] r ^{170}Yb could be used (12) as a reference in [illegible] ^{176}Hf pair.

[illegible] fig. 1) decays to the daughter ^{170}Yb through [illegible] d 1st excited state of a very short [illegible]

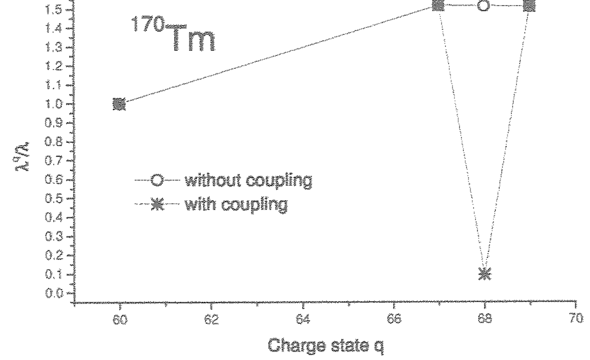

Fig. 2. Charge state dependence of $c\beta$ decay rate in ^{170}Tm.

rate smoothly increases with the increasing of the Q-value as one can see in circles in fig 2. However, if one considers an electron-nucleus spin coupling in the H-like system, assuming a statistical distribution of the resulting states, the conservation of the total spin will result in the points shown in stars in fig 2, where consequently the decay rate decreases unfavorably. This coupling can be easily made up comparing the β^- decay rates of bare, H-like and He-like.

In the bound β-decay side, one may expect this process to be the source of the large enhancement of ^{170}Tm decay rate (12). A calculation of this rate in typical s-process conditions (4), revealed a modest enhancement up to 5 T_8 ($\sim$ 40 keV), but no predictions exist for highly charged state. There also the bound-β-decay rate ratio between bare and H-like parents should be 1/2, and any deviation from this factor will be a clear signature of electron-nucleus spin coupling.

2.2 β^+ decay of ^{136}La

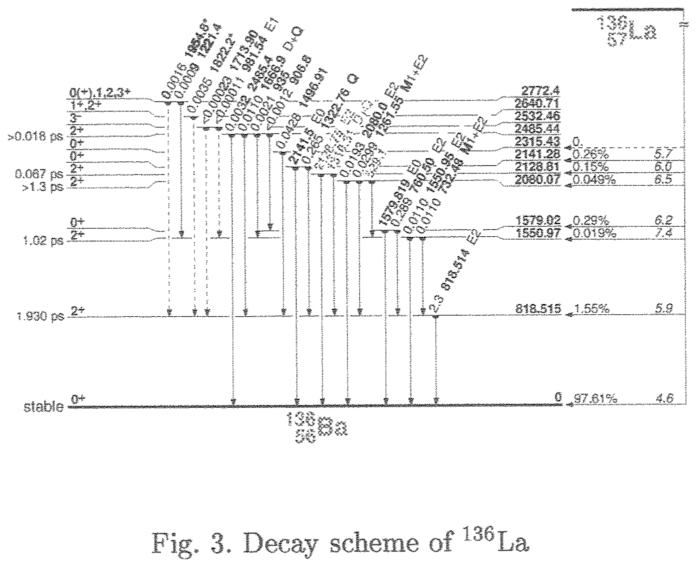

Fig. 3. Decay scheme of ^{136}La

Two factors constraint the lifetime measurements with Schottky spectrometry : *i*) the nuclear lifetime should be above the ion cooling time (10 s), *ii*) the Q-value should also be larger than the resolving power. Many isotopes fulfill these conditions, and among the interesting isotopes one can investigate ^{136}La (1^+, 9.87 m, fig. 3), whose ground state decays by EC (74%) and β^+ (36%). These comparable branching ratios allow us to directly and simultaneously study these 2 processes.

The ^{136}Ba excited states fed by the decay of ^{131}La, have very short lifetimes that favorably will not contaminate the Schottky spectrum as shown in fig 4. This figure presents a scheme of such decay of bare (top) and H-like (bottom) ions of ^{136}La. Once cooled, the ions give rise to narrow peaks ($\sim$ 20 Hz) which provide, in one single spectrum (250 kHz), a clear separation between the peaks of parent/β^+-daughter (187 kHz) in one hand, and parent/EC-daughter (230 Hz) in the other hand. As the peak area is proportional to the number of ions, one can follow in time the evolution of the populations of the different ion species stored in the ESR.

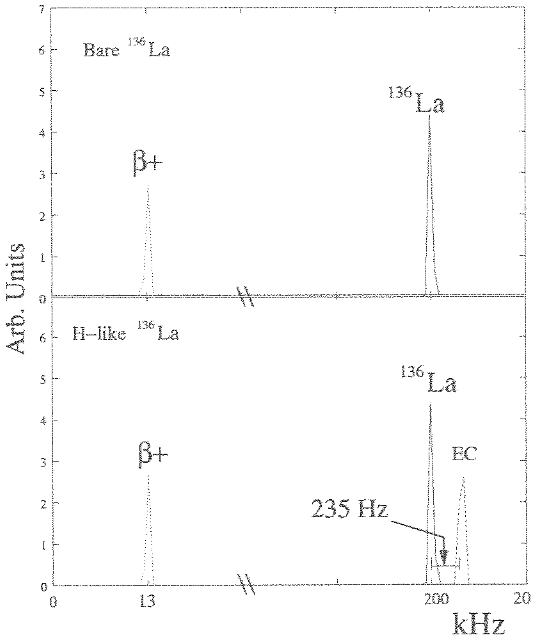

Fig. 4. Scheme of a Schottky spectrum of ^{136}La and its β^+ and EC daughters, in the case of bare (up) and H-like (down) ^{136}La.

3 Counting rate estimates

For this experiment, we propose to study β-decay of ^{170}Tm and ^{136}La isotopes by fragmenting a 800 MeV/u beam of ^{174}Yb on a 10 g/cm^2 ^{9}Be target at the FRS target-station. The projectile fragmentation cross section (EPAX) of a 10 mb and 0.1 mb respectively, and with the available intensity of the primary beam (10^9 /spill), the upper limit of the isotope production will be 10^7 ^{170}Tm/spill and 10^5 ^{136}La/spill. These values are favorable because of the decay rates that amount to 10^{-3} for ^{136}La and some 10^{-8} in the case of ^{170}Tm where we can operate the ESR in the stacking mode which allows to store up to 1×10^{8} particles. After in-flight separation by the FRS, the fragments will be injected into the ESR ring, stored and electron-cooled.

4 Beam-time request

The 1st FRS tuning and isotope identification require **2 shifts**. The optimization of the FRS-ESR injection requires **1 shift**. **2 shifts** are need to set up the ESR as well as the Schottky diagnosis hardware/software. The change of the charge state as well as the isotope change will be operated through the SIS energy when the setup of the FRS and the ESR will be kept unchanged. As we have to separately study 2 isotopes over 4 charge states a minimum of **16 shifts** are needed. This experiment requires a total of **21 shifts**. We have to mention that the ESR operation will be : one injection followed by 10-20 min time measurement.

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