I did something cool at CERN - ISOLDE

by

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Thesis

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Abstract

To my family, for all their support and encouragement!

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Collaboration details

The sorting and analysis code used in this thesis has been developed at CERN-ISOLDE and can be found at https://github.com/Miniball/MiniballCoulexSort

The code for theoretical predictions of energy used in the calibration was developed by Liam Gaffney who is working at ISOLDE and has to do with analysis of data from Miniball and ISS. kinsim can be found here https://github.com/lpgaff/kinsim

Some calibration code is based on the codes of Ville Virtanen and Liam Gaffney.

Other code/scripts have been written by the author. C++ / Python.

Trond Wiggo Johansen

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Contents

Chapter 1

Introduction

Test [1]

Test 2 [?]

kinsim [2]

The experiment has been done before, with lower energy (and another target), Malin Klintefjord. http://urn.nb.no/URN:NBN:no-56121

Experiment conducted 8th - 14th of August 2017.

Chapter 2

Theory?

Deformation.

Shape coexistence?

Chapter 3

Coulomb excitation experiment

Table 3.1: Acronyms and abbreviations.

PSB	Proton Synchrotron Booster
ISOLDE	Isotope Separator On-Line DEvice
GPS	General Purpose Separator
HRS	High Resolution Separator
EBIS	Electron Beam Ion Source
REXEBIS	Radioactive beam EXperiment EBIS
RILIS	Resonance Ionization Laser Ion Source
HIE-ISOLDE	High Intensity and Energy upgrade
RIB	Radioactive Ion Beam
ENSAR2	European Nuclear Science and Applications Research - 2
ISOL	Isotope Separator On-Line
Linac	Linear accelerator
ADC	Analog-to-Digital Converter
TDC	Time-to-Digital Converter (or time digitizer)
Coulex	Coulomb excitation

Oppgavens mål:
The ISOLDE facility at CERN has been upgraded to provide higher energies and intensities for radioactive ion beams. A new experiment to study 140Sm was performed in the summer of 2017. The goal of the experiment was to measure electromagnetic transition probabilities and electric quadrupole moments for several excited states in 140Sm by measuring Coulomb excitation probabilities. A large data set was obtained using silicon detectors to determine the energies and angles of scattered particles, and germanium detectors to measure gamma rays from excited states in 140Sm.

The goal of the master thesis is to analyze the data from this experiment. The required tasks include development and improvement of data analysis software to determine Coulomb excitation yields. These yields will then, in a second step, be compared to theoretical calculations and transition probabilities and quadrupole moments will be extracted using chi-square minimization procedures.

Prosjektbeskrivelse (omfang 60 studiepoeng):
The shape of an atomic nucleus is determined by a delicate interplay between macroscopic (liquid drop) properties and microscopic shell effects. Nuclei with filled proton or neutron shells (i.e. magic nuclei) are generally spherical in shape, whereas nuclei with open shells gain energy by assuming a deformed shape. Depending on the occupation of specific orbitals, the nuclear shape can change drastically by adding or removing protons or neutrons. Certain nuclei exhibit shape coexistence, i.e. the coexistence of quantum states that correspond to different shapes. Because the shape of a nucleus is so sensitive to the underlying nuclear structure and to changes of the proton and neutron numbers, the excitation energy, or the angular momentum, observables related to the nuclear shape are used as benchmarks for theoretical models.

Nuclei in the rare earth region, and in particular the chain of samarium isotopes, exhibit a variety of shape effects. The Sm isotope with closed neutron shell at N=82, 144Sm, is spherical in shape. Adding neutrons to 144Sm changes the deformation to an elongated (prolate) quadrupole shape. The transition from spherical to prolate shape, which occurs for 152Sm at N=90, can be interpreted as a shape-phase transition. Flattened (oblate) quadrupole shapes are predicted by theory to occur below the N=82 shell closure. An earlier experiment studying 140Sm at CERN-ISOLDE found triaxial shape for this isotope, i.e. a shape where all three principal axes of the ellipsoid have different lengths. 140Sm can therefore be considered to lie at the critical point of a phase transition from spherical to deformed, and from prolate to oblate shape.

Foreløpig tittel:
Coulomb excitation of 140Sm

Metoder som tenkes benyttet:
Multi-step Coulomb excitation with radioactive beam, isotope separation on-line technique, nuclear spectroscopy, particle-gamma and particle gamma-gamma coincidence analysis, advanced chi-square minimization procedures.

3.1 ISOLDE

The ISOLDE Radioactive Ion Beam facility

Nuclear physics facility at CERN.
ISOLDE http://isolde.web.cern.ch
REX-ISOLDE http://rex-isolde.web.cern.ch
RILIS http://rilis.web.cern.ch
HIE-ISOLDE http://hie-isolde-project.web.cern.ch, technical design http://cds.cern.ch/record/2635892?ln=en, direct to doc: http://cds.cern.ch/record/2635892/files/HIE-ISOLDE_TDR.pdf
MINIBALL http://isolde.web.cern.ch/experiments/miniball and https://www.miniball.york.ac.uk/wiki/Main_Page
ENSAR2 http://www.ensarfp7.eu
Test [3], copyright: https://copyright.web.cern.ch
CERN Document Server https://cds.cern.ch

3.1.1 Beam production

ISOLDE experimental hall:

$$\begin{aligned} \mathrm{p}^+ \to\ & \mathrm{Ta} \to \text{(Produces the chart of nuclides up to Ta)} \to \mathrm{GPS} \to \\ & \mathrm{RILIS} \to \mathrm{REXEBIS} \to \text{HIE-ISOLDE} \to \mathrm{MINIBALL} \end{aligned}$$

Protons from the PSB comes into the ISOLDE facility and hit a production target of tantalum, producing the elements in the chart of nuclides up to tantalum. The fragments travels onward to the GPS where the mass of $A = 140$ is selected. RILIS selects samarium with laser. REXEBIS excites the nucleus in three steps ionizing the atom, which leaves the nucleus in a high charge state. The HIE-linac accelerates the beam through the beam line and magnets bend the beam into MINIBALL.

Magnets....

Ebis: charge breader: release beam with certain energy.

high-performance charge breeder (CB). CB based on the Electron Beam Ion Source (EBIS) technology – an EBIS Charge Breeder (ECB)

HRS not in use for this experiment?

HIE-ISOLDE (Superconducting Linac Upgrade): Linear accelerator, HIE-linac

Post-accelerated beams ISOLDE http://iopscience.iop.org/article/10.1088/1361-6471/aa78ca

ISOLDE actually uses the most protons at CERN [ref?].
Very pure beam

3.1.2 Target

^{208}Pb was chosen as a target. Want high Z so that the probability of excitation is high. Not enough beam energy to excite ^{208}Pb.

Contamination... finger print [picture]

3.1.3 Miniball

Pictures https://cds.cern.ch/record/844871?ln=en

3.1.4 Particle detector, DSSSD

16 rings, 12 strips effectively (24 strips, 12 pairs with two strips making a pair)

3.1.5 γ detectors, HPGe

24 six-fold segmented

Cryo-modules

3.2 Experimental setup

^{140}Sm Coulomb excitation experiment.
Experiment code: IS558
Ta: tantalum (Z = 73)
Sm: samarium (Z = 62)
Pb: lead (Z = 82)

Beam: ^{140}Sm(4.65 MeV/u, 651 MeV)
Target: ^{208}Pb
Small angle: Forward scattering: Larger distance, weaker EM-field, less excitation probability.
Large angle: Backward scattering: Closer distance, stronger EM-field, higher excitation probability.

Chapter 4

Data analysis

ROOT: analysere data
kinsim3 + SRIM
+Experiment code: IS553
Ni: nickel (Z = 28)
Ba: barium (Z = 56)

particle-gamma and particle-gamma-gamma coincidence

4.1 Calibration

4.1.1 Particle detector

ADC: Analog to digital converter (Mesytec)
TDC: Time to digital converter
DSSSD: Double-Sided Silicon Strip Detector $\Longrightarrow$ CD
must remove the inner ring from data analysis because of damage

$$gain = \frac{E_{Sm} - E_{Pb\ or\ Ni}}{Ch_{Sm} - Ch_{Pb\ or\ Ni}}$$

$$offset = E_{Sm} - gain \cdot Ch_{Sm}$$

in keV.

4.1.2 Gamma detectors

DGF: Digital γ finder

4.2 Doppler correction

Chapter 5

Experimental results

Chapter 6

Discussion

Chapter 7

Summary and outlook

Appendices

Appendix A

Some Appendix

Appendix B

Some other appendix...

Bibliography

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