Coulex-RDDS experiments with radioactive beams

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Recently it has been shown that the combination of Coulomb excitation and the recoil distance Doppler shift (RDDS) technique, in the following called Coulex-RDDS, is a powerful tool for measuring lifetimes of excited low lying nuclear states. Here the Coulomb excitation is only used to excite the nuclear states and the lifetimes are determined with the RDDS method. Therefore the Coulex-RDDS technique is an independent and alternative technique to the determination of transition probabilities from the evaluation of measured Coulomb cross sections. The main advantage of the Coulex-RDDS technique results from two facts:

1. The feeding of Coulomb excited levels is known and thus the severe problem inherited to the standard RDDS technique after compound fusion reactions is eliminated.

2. The RDDS techniques allows a direct measurement of the level lifetimes and the complex analysis of cross sections where often many unknown matrix elements have to be fitted is avoided.

A direct comparison of the Coulex-RDDS technique and the standard Coulomb excitation [1)] revealed consistent results for yrast states at a high level of accuracy (2%). For non yrast states in some cases discrepancies were found pointing to problems associated with the analysis of the Coulomb cross sections [1)]. For a Coulex-RDDS measurement it is sufficient to measure particle gated singles γ spectra, a fact which becomes essential for experiments with radioactive beams where one deals with extremely low beam intensities.
The use of radioactive beams opens up a large new field where this method can be employed.
Thus it becomes possible to study very interesting physical phenomena in nuclear regions where up to now no or only very little experimental data are available. E.g., triaxiallity, shape coexistence and new dynamical symmetries could be investigated in neutron rich nuclei which can not be reached by compound fusion reactions.
New dynamical symmetries at the critical point of shape phase transitions were discussed recently by F. Iachello [2)]. One of these symmetries, called E(5), is related to a U(5)-SO(6) shape phase transition (transition from vibrator to a γ soft nucleus). Experimental evidence of such a symmetry was found in ^{134}Ba[3)].
The corresponding symmetry for the transition of a rotational to a vibrational nucleus is called X(5) and ^{152}Sm is considered to be the first example of this new class of symmetry [4,5)]. These symmetries represent entirely new paradigms of nuclear structure, giving completely analytic and parameter-free descriptions

of energies and transition rates. It is crucial to test them in other nuclei. Absolute transition probabilities are sensitive observables for such tests.

A further interesting physical topic to which a lot of experimental and theoretical work was devoted recently is the investigation of spherical, oblate and prolate shapes coexisting at low excitation energies in the neutron deficient Pb and Po isotopes, e.g., in ^{186}Pb [6)]. Heavy radioactive beams which can be produced at GSI via fragmentation offer the unique possibility to investigate this interesting phenomenon. The present experimental knowledge is rather limited especially as far as transition probabilities are concerned. The spectroscopy after multiple Coulomb excitation of the radioactive projectile offers a great chance to populate the often unknown excited $0^+_{2,3}$, $2^+_{2,3}$, and $4^+_{2,3}$ states as well as to measure the corresponding lifetimes. These experimental data are crucial for the understanding of the involved interaction between the different nuclear excitation modes.

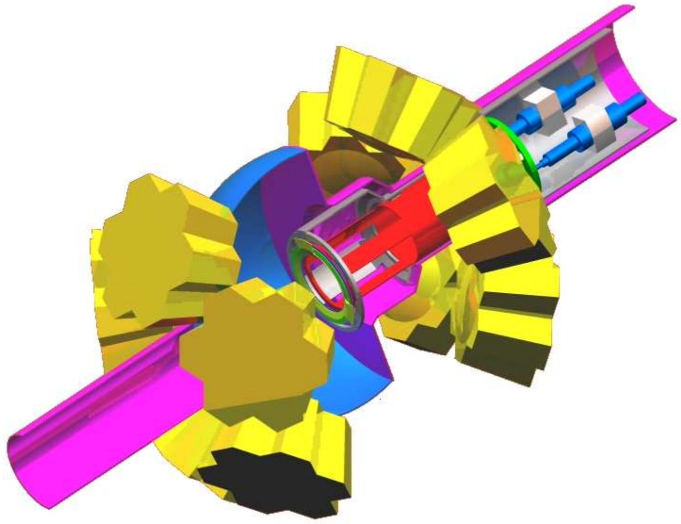
Experimental considerations:

Fast radioactive beams which can be produced at the GSI have to be separated in the FRS and slowed down to about 10 MeV/u. The projectiles will be Coulomb excited in a first target foil of a plunger device. In a second degrader foil the exited projectiles will be slowed down from about 12% to 9% of c. The degrader foil corresponds to the conventional stopper foil of a standard plunger set-up. The flight time of the projectiles between the two foils can be varied by varying the target-to-degrader distance. γ-rays emitted by the projectiles in front and after the degrader foil can be distinguished by the different Doppler shifts. A complication is caused by the Coulomb excitation of projectiles in the degrader foil. γ-rays emitted from these nuclei show up in the spectra at the retarded component (R^T) of those nuclei which were Coulomb excited in the target foil. The two components of one peak can be separated by either measuring the recoiling degrader ions in coincidence with the γ-rays or by choosing a large target-to-degrader distance where the component R^T has vanished.
In order to realize such an experiment a plunger device has to be build with very large target and degrader foils (4-10 cm in diameter) because of the large waists of the slowed down radioactive beams. It is also needed to track the beam particles in coincidence with the γ-rays. The Ge detectors should be positioned at extreme forward and backward angles in oder to obtain separated Doppler shifted components. The total γ-ray efficiency should reach a value of about 7.5%. A possible set-up using Euroball cluster detectors without BGO shields is shown in the figure below. Estimated count rates for transitions depopulating states excited with cross sections of about 1 barn amount to 2000 cnts/h assuming a beam intensity of 10^5 p/sec.

The differential plunger:

The concept of a differential plunger has been introduced in [7)]. Different to the conventional plunger, an additional degrader foil is positioned between the target and stopper foils. In the case of the set up described above the additional degrader(in the following called degrader(1)) is positioned between the target and the degrader foil, degrader(2). The distance between the target and degrader(1) can be varied whereas the distance between degrader(1) and degrader(2) is fixed. Such a set-up generates three components of a γ transition from which the corresponding level lifetime can be directly determined. If the target-to-degrader(1) and degrader(1)-to-degrader(2) distances are properly chosen for the lifetime of interest only one target-to-degrader(1) distance is needed. With the differential plunger about a factor of two in beam time can be saved. Further details of the differential plunger can be found in [7].

Summing up Coulex RDDS measurements with radioactive beams seem to be feasible. Estimates on the beam intensities, e.g., for ^{188}Pb which is a promising candidate for the investigation of the above mentioned triple shape coexistence amounts to 10^{5-6} p/sec. Similar beam intensities are estimated for ^{192}Po where the same physics can be studied but the present experimental knowledge is much poorer.



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