Exploring nuclear structure of medium mass nuclei by measuring electromagnetic moments using Coulomb excitation technique

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Introduction

The measurements of electromagnetic moments and transitions rates represents one of the most sensitive probes to investigate nuclear structure and a direct method to study nuclear collectivity and shapes. The Coulomb excitation technique is useful to excite low lying collective states selectively with cross sections that are a direct measure of the electromagnetic matrix element. Coulomb excitation was pioneered in the 1950's and was extensively used during the 1960's and 70's when heavy ion accelerators and high resolution germanium detectors became readily available.

This thesis aims to investigate the nuclear structure of ^{120,122,124}Te isotopes by measuring the transition probabilities and magnetic moments. The tellurium nuclei with 52 protons lies between the spherical nuclei at Z = 50 and deformed Xe and Ba nuclei. At low spin the Te nuclei are considered to be one of the best examples of quadrupole vibrators. This interpretation comes from the reason that close to twice the energy of the first 2^+ state a multiplet of 0^+, 2^+ and 4^+ states is observed. Furthermore, the energy of the yrast 6^+ state is almost three times the energy of the 2^+ state, as expected in the vibrator picture. This observation, is in contrast to the measured quadrupole moments Q_{2+} for the doubly even Te isotopes. These quadrupole moments can reach 60% of that predicted by the symmetric rigid rotor.

This thesis work is divided into two parts. The first part is dedicated towards the measurement of electric moments of ^{120,122,124}Te nuclei to probe their nuclear structure. The second part is focussed towards the development of a setup to measure the magnetic moments of these nuclei.

Transition Probability Measurement

Both the set of experiments were performed in the GDA beamline at Inter University Accelerator Centre (IUAC) in New Delhi. In the first measurement ^{58}Ni beam at 175 MeV was used to Coulomb excite the three targets of ^{120}Te,^{,122}Te and^{,124}Te, respectively. All targets were of nearly equal thickness ~ 0.15 mg/cm^2 evaporated onto a thin carbon backing of 25-30 $\mu g/cm^2$. An annular gas-filled parallel-plate avalanche counter (PPAC) was placed downstream of the target to detect both the scattered projectiles as well as the recoiling target nuclei in an angular range of $15^\circ \leq \vartheta_{lab} \leq 45^\circ$. De excitation γ -rays emitted after Coulomb excitation were measured with four clover (Ge) detectors mounted at $\vartheta_\gamma = 135^\circ$ with respect to the beam direction. To avoid any systematic errors the nucleus of interest was measured with respect to a very accurate reference nucleus. In order to avoid any systematic error, both ^{120}Te and ^{122}Te were exposed to the beam for ~ 4 hours duration alternately.

A precise Doppler correction was performed event by event for the measured γ-rays for target and projectile excitation. The excitation strength of the 2^+ state in the different isotopes were determined for distant collisions, with the first excited 2^+ state in ^{58}Ni used for normalization. The double ratio $[I_\gamma(^{120}\text{Te})/I_\gamma(^{58}\text{Ni})]/[I_\gamma(^{122}\text{Te})/I_\gamma(^{58}\text{Ni})]$ of the γ-ray yields were determined. This γ-ray ratio allowed a precise measurement of the B(E2↑) of ^{120}Te. For ^{120}Te $B(E2;\ 0^+_{g.s.} \rightarrow 2^+)$ value of 0.666(20) e^2b^2 [1] was extracted which yields a collectivity of 40 single particle units. The experimental results were also compared with Large Scale Shell Model (LSSM) calculations and good agreement was found. The difference between two proton and two proton-hole configurations was also investigated by plotting $B(E2;\ 0^+_{g.s.} \rightarrow 2^+)$ values for tellurium and cadmium versus the neutron number. Both distributions had same dependence on the neutron number. The B(E2) ratios normalized to $B(E2;\ 0^+_{g.s.} \rightarrow 2^+)$ were also determined for the higher lying states to probe the nuclear structure of ^{120,122,124}Tenuclei. IBA-2 [2] calculations were also performed and these could explain the energy spectra as well as the measured E2 transition probabilities close to the O(6) limit. It showed an unusual rotational behaviour for these isotopes and also all the experimental results can be quite well described by a soft triaxial rotor.

Magnetic Moment Measurement

To measure the g factors of Te isotopes a set-up based on the transient field technique was developed at the University of Delhi and IUAC [3]. For levels with lifetimes of the order of 10^{-12} s, magnetic fields of the order of *MTesla* have to be generated to produce a measurable precession. Such fields cannot be produced on a macroscopic scale and one has to adopt the technique of transient magnetic field to produce such fields on a microscopic level. The associated magnet power supply and control system was also fabricated in house at IUAC [4]. The set-up essentially consists of a target chamber made of aluminum with a built in electromagnet and a liquid nitrogen Dewar. The magnet used is a C frame electromagnet which can produce a magnetic field of the order of 1000 Gauss. The pole pieces of the electromagnet were designed in a special way with a slit so that the target can be placed between them and will face the maximum uniform magnetic field. One of the most important and crucial ingredient in such experiments is the preparation of ferromagnetic target with a uniform magnetization property. The ^{nat}Gd ferromagnetic target was prepared using rolling and annealing procedure in the Target Lab of IUAC. The magnetization of these Gd foils was investigated using a Vibrating Sample Magnetometer (VSM) at the University of Delhi. The magnetic moment observed for one of the Gd foil is ≈ 5 μB/atom.

Several test experiments [5] were performed by bombarding ^{28}Si beam at 98 MeV on a ^{nat}Gd ferromagnetic target. The target consisted of 6.12 *mg*/*cm*2 layer of ^{nat}Gd stuck to a thick copper backing of thickness 4.98 *mg*/*cm*2 using a thin layer of indium. The motivation for using Gd as the ferromagnetic host came from the fact that it showed better magnetization properties with respect to iron. Since the curie temperature of Gd is 293 K the target was also cooled down during the experiment. The de-exciting γ-rays were detected in four HPGe detectors placed symmetrically with respect to the beam direction at 60°in the forward and the backward direction. The back-scattered beam ions were detected in a pair of solar cells. From the particle-γ angular correlation the slope parameter was extracted which shows the sensitivity of this technique [6]. The precision angle was obtained. The values of the net precision are directly proportional to the g factor of the corresponding states.

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