Trapping radioactive ^{146}Eu in a Paul Trap for studying ground state properties of nucleus

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Introduction

The nuclear ground state properties such as spin, electromagnetic moments and charge radii of stable and radioactive nuclei can be measured using LASER spectroscopic techniques based on the precise measurements of atomic Hyperfine Structure [1,2]. In these studies, Ion Traps [3] play an important role as atomic ions are confined for a long time, enabling accurate and repeated measurements under controlled environmental conditions. Since ions can be cooled by various techniques in an ion trap, spectral broadening is drastically reduced and HFS (Hyper Fine Splitting) caused by interaction of the atomic electrons with the nucleus can be measured with very high precision using LASER spectroscopic techniques.

Hyperfine Anomaly also known as Bohr-Weisskopf (BW) effect, reflects changes in the distribution of nuclear magnetization and Breit-Rosenthal (BR) effect reflects distribution of charge, in extended nucleus and these are the topics of current interest. Hyperfine anomaly is pursued by measuring the magnetic part of the HFS with high accuracy on a long chain of isotopes using LASER spectroscopic techniques in Ion Traps [4, 5, 6]. Europium has been selected for study of HFS as it has a long chain of stable/unstable isotopes which are long lived, and have non-zero nuclear spin. Trapping of stable isotopes and extensive work therein has already been reported [7].

In this work, radioactive ^{146}Eu isotope was prepared at Variable Energy Cyclotron Centre (VECC) using room temperature cyclotron and this isotope has been trapped in AMPD, Bhabha Atomic Research Centre (BARC) using a Paul Trap for pursuing high precision Atomic Physics studies. For Laser spectroscopic measurements with high accuracies and precision, confinement of ions is a pre-requisite for Hyperfine Anomaly studies.

Paul Trap

In a Paul trap [3], ions are confined using an rf potential along with a dc potential. Potential is applied between the three sets of electrodes that basically comprise an ion trap. The equations of motion for the ion trajectories is in the form of Mathieu equations

$$\frac{d^2 x_i}{d\tau^2} + (a_i - 2q_i \cos 2\tau) x_i = 0 \qquad (1)$$

for i = r, z

and the scaled time $\tau = \frac{1}{2}\Omega t$.

The stability region wherein the ions can be confined depend on the trapping parameters (basically here the ion trajectories have finite amplitudes) and are given as

$$-a_z = 2a_r = \frac{8eU_{dc}}{m\Omega^2 r_0^2}$$

$$q_z = -2q_r = \frac{4eV_{ac}}{m\Omega^2 r_0^2}, \qquad (2)$$

where m is the mass and e is the charge of the trapped ion, Ω is the frequency of the trapping field.

In the pseudo potential approximation, ion trajectory consists of the low frequency secular motion $\omega_{r,z}$ superimposed with a weakly modulated micromotion at the rf frequency Ω. Under these conditions, the ion secular frequency is given as $\omega_i=\beta_i(\Omega/2)$, where β_i is approximated to;

$$\beta_i^2 = a_i + \frac{q_i^2}{2} \qquad (3)$$

Experiment

In order to produce ^{146}Eu, 37 MeV alpha beam from Room Temperature Cyclotron of VECC was bombarded on ^{144}Sm target and recoil product, ^{146}Gd produced via (α,2n) reaction was collected on a aluminum catcher. Gd nuclei thus produced were radio-chemically separated from Aluminum catcher, turned into concentrated solution and transported to AMPD, BARC, Mumbai.

Radioactive ^{146}Gd ($\tau_{1/2}$= 48.27 days) decayed by β^+ emission producing ^{146}Eu. The solution containing $^{146}Gd/^{146}Eu$ was dropped through a micropipette onto the filament which is shaped in the form of a boat and dried under an IR lamp. The filament with radioactive isotopes was placed inside the Paul trap, evacuated to ultra high vacuum (5×10^{-9} mbar) and later ^{146}Eu was loaded in the Paul trap by thermionic emission (at 900 ^oC for ~1min). By providing appropriate voltages to the trap electrodes, ^{146}Eu was confined in the Paul trap. Nitrogen as a buffer gas was introduced up to 1.35×10^{-4} mbar, for cooling the trapped ions. Later, Barium ions was loaded and confined in the trap to serve as a reference.

Detection of trapped ions

Among several trapped ion detection techniques, the electronic detection method measures the response of the mass dependent trapped ion oscillation frequencies using a tank circuit coupled to the ion trap.

For preliminary testing of the setup, $^{138}Ba^+$ ions were trapped. For $^{146}Eu^+$ trapping, RF at a frequency of 500 kHz and amplitude of 468V was used along with a dc voltage that was ramped at 5Hz and 5V amplitude. To detect ions electronically, the tank circuit is resonated with an excitation RF at 54.55 kHz frequency. The detected signal of 25mV strength was obtained and the position of the peak was at U_{dc} = 2.25V. From these operating parameters the calculated ion oscillation frequency for $^{146}Eu^+$ ions in the axial direction is ω_Z~55.0 (±0.5) kHz and this matches with the resonant excitation frequency within the estimated error, confirming trapping of $^{146}Eu^+$ ions.

Since the ion oscillation frequency is mass dependent, it is experimentally observed by trapping different ion species at different set of trapping potentials (V_{ac} and U_{dc}), and following the equi-frequency lines at 54.55 kHz. Fig 1 clearly shows that when $^{138}Ba^+$ is trapped at a given set of trapping potentials, it follows an equi-frequency line different from $^{146}Eu^+$ and also $^{39}K^+$ (which is an impurity element in the Ba sample). Theoretical evaluations of the potentials for $^{146}Eu^+$, $^{138}Ba^+$ and $^{39}K^+$ carried out keeping the axial ion oscillation frequency fixed at 54.55 kHz matches with our experimental results. This confirms that we have trapped and detected the radioactive $^{146}Eu^+$ ions. The number of trapped ions is estimated by fitting the electronically detected signal profile to the ion response curve of the tank circuit [7]. In our experiment the estimated number of trapped $^{146}Eu^+$ ions is 1.2×10^5 ($\pm10^4$).

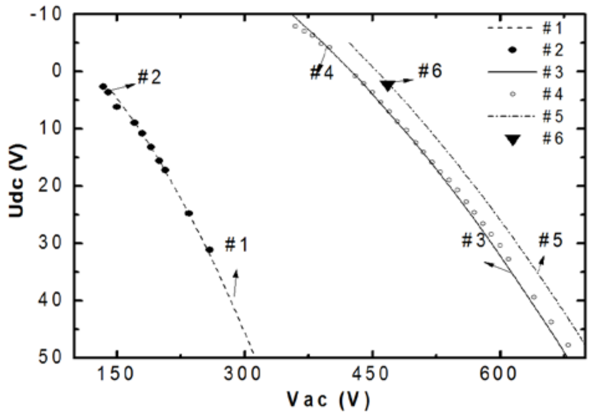

Fig 1. Plot of the equi-frequency lines in terms of applied voltages, for $^{39}K^+$ (Theoretical **#1**, Experimental **#2**), $^{138}Ba^+$ (Theoretical **#3**, Experimental **#4**), $^{146}Eu^+$ (Theoretical **#5**, Experimental **#6**).

Conclusion

We have produced and successfully trapped the short lived, radioactive ^{146}Eu isotope in a Paul trap. The experiment confirmed that the trapped ions were $^{146}Eu^+$ and the number of ions was found to be ~ 1.2×10^5 ($\pm10^4$). These preliminary experiments are encouraging and pave a way for future Laser spectroscopic experiments on short lived radioactive nuclei for studying ground state nuclear properties.

References

[1] A. Bohr, V. F. Weisskopf, Phys. Rev., **77** (1950) 94.
[2] E. Arimondo, et al., Rev. Mod Phys., **49**,1977, 31
[3] F.G.Major, V.N.Gheorghe, G.Werth Charged Particle Traps , Germany 2005.
[4] J. S. Grossmann et al. Phys. Rev. Lett. **83**, 1999,935,
[5] J. R. Persson, Phys. Scr. **76**, 2007 ,449
[6] K. Enders et al. Phys. Rev. **A 52**, 1995, 4434
[7] S. Bhattacharyya et al. Pramana – J. Phys. **67**, 2006, 1087