Design of fluorescence cell for isotope shift measurements by atomic-beam laser spectroscopy

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High resolution laser spectroscopy coupled with high sensitivity is important to investigate properties of the ground and isomeric states of nuclei away from stability. The measurement of isotope shifts (IS) and hyperfine structure (Hfs) yields information about changes in nuclear charge distribution and multipole moments in an isotopic chain. This provides detailed insight into collective and single particle properties of the nucleus. High sensitivity is important since these nuclei are produced in trace quantities while high resolution makes it possible to detect small differential changes in mean square charge radii between the isotopes. To carry out laser spectroscopy with good sensitivity, a fluorescence cell incorporating various features suitable for investigation of stable and long-lived radioisotopes has been designed and fabricated [1]. This versatile cell also has a provision to study of online species produced at accelerators. In the present work, high sensitivity together with high resolution using atomic-beam laser spectroscopy has been explored.

The development of Laser Induced Fluorescence (LIF) technique for offline studies is presented here. The fluorescence cell consists of a vacuum chamber in the form of a cube having six ports; one on each of the faces. The ports are provided for entry and exit of the laser beam, fluorescence detection and for the vacuum pump. When used in online mode, one port provides entry of ion beam from accelerator into the cell and one port is for the entry of buffer gas as well as liquid nitrogen cooling. When used in offline mode, these ports are replaced with a heater assembly (for atomic beam production) and a blank flange.

To improve the sensitivity of detection, it is important to minimise the background due to various effects. The stray light coming from various external sources is blocked as far as possible. The other source of background is due to scattering of the laser at the windows at entry and exit of the long arms of the fluorescence cell. The extended arms (of length 30 cm) are fitted with collimators to reduce the contribution of scattered laser light. The collimators are disks with apertures which fit the inner diameter of the entry and exit arms close to tolerance. It is found that the major contribution to the scattering of the laser is due to the window at the entry arm. The laser scattering is considerably reduced when two collimators each with 2 mm apertures, both at the entry and the exit arm, are introduced [1]. Further reduction can be achieved by using a disk with an octogonal aperture of 2.0 mm in diameter and two subsequent disks with gradually increasing apertures, upto a diameter of 2.5 mm. The exit arm has two apertures inside, with diameters 2.7 mm and 3.0 mm. These long arms are provided with optical windows at a small angle with respect to the axis of the laser beam to prevent entry of the reflected light in the region of fluorescence detection. Flat quartz windows coated with a wide band antireflection coating are used for the entrance window.

An oven has been specially designed for atomic beam production for the offline experiments. The small heater designed for offline experiments is used in place of the ion beam entry. The heater assembly is placed on the top port of the fluorescence cell in offline mode. It is essentially a stainless steel flange and has two electrodes. The electrodes are centered on the flange by means of a nylon ring which also provides electrical isolation. The titanium strip in the form of a boat,

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where the sample is placed, is fixed between the two electrodes. A K-type thermocouple is placed in contact with the Ti strip to measure the temperature attained by the Ti strip. It also monitors the equilibrium temperature. The background due to the heated Ti strip is avoided by using a heat shield around the electrodes. The heat shield is a cylinder made of stainless steel with a lid. The lid of the heat shield has a slit of width 0.5 mm and a length of 10 mm. This slit arrangement is useful in case of small sample size.

Experiments have been carried out in the fluorescence cell using stable ^{133}Cs to determine the sensitivity of the setup and improve the same so that nuclei (stable and long-lived radioactive) can be studied. The testing and standardisation of the setup is done in offline mode using ^{133}Cs isotope, which provides an excellent surrogate for radioactive alkali isotopes. We propose to extend this technique for the study of long-lived products (^{127,129}Cs) to be prepared in the form of cesium nitrate. In the present work, we have standardised the LIF experiment using stable Cs in the same chemical form. The solution (typically containing 100 mg of ^{133}Cs) is dispersed on the titanium boat, loaded in a specially designed resistive heated oven and heated to about 100-200 ^{o}C to generate vapour of atomic cesium. The vapour is collimated appropriately to form a cesium atomic beam. The excitation source used is a single mode ($\sim$ 1 MHz) external cavity tunable diode laser tuned to the 852.1 nm transition (6s $2S_{1/2} \rightarrow$ 6p $2P_{3/2}$) of cesium using a cesium reference vapour cell. The resonance fluorescence of cesium in the interaction zone is measured using collection optics and a photomultiplier tube with the former consisting of an imaging lens system and a slit aperture. Fluorescence spectrum is generated by mode hop-free scanning of the diode laser across 6s $2S_{1/2} \rightarrow$ 6p $2P_{3/2}$ transition.

The primary objective of the present investigation is to optimise the sensitivity. Cs atoms have been detected up to about 10 mg of initial sample size using titanium (in the form of a boat) as the reducing agent. The sensitivity can be enhanced by using the slit-collimator arrangement in the heater assembly, and it is expected that Cs atoms one order of magnitude smaller sample size can be detected. Starting with this amount of sample size, the number of atoms that could be detected would be $\sim 10^6$ atoms per cm^3. The sensitivity and resolution of the laser induced fluorescence setup is sufficient for the IS and Hfs measurements [2]. Development of the LIF setup and the fluorescence cell to achieve better sensitivity is underway.

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References

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