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Development of a multipurpose beam foil spectroscopy set-up for the low cross-section measurements

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ABSTRACT

A multipurpose facility for low cross section measurements has been developed at Inter University Accelerator Centre, New Delhi, India. The facility consists of a multipurpose miniature chamber equipped with 1 m focal length normal incidence Monochromator and charge coupled device based detection system which has been aligned to realize the best resolution of the spectrometer. The chamber in this facility collects radiation 100 times more efficiently from the older system, without using any extra focusing mirror assembly. It is ensured to have the provision of mounting an X-ray detector and the spectrometer transverse to the beam direction simultaneously in the same chamber. The atomic spectroscopic studies can be performed by interaction of ions beams with both thin foil and gas targets. Provision for using photomultiplier tube instead of charge coupled device, is employed in the system depending on the condition of the source strength or other detection issues. We observed the essence of a very weak atomic phenomenon, a triply excited autoionizing forbidden transition, using the above facility to demonstrate its capability for measuring such low cross section phenomena. The present developed facility covers a large spectroscopic region from X-rays to the near infrared (0.1–10,000 Å).

1. Introduction

Beam-foil spectroscopy (BFS) is popularly known for its potential in producing highly stripped ions and excited states [1] including various ionic states up to H-like ions with one or multi electrons in Rydberg [2,3] or continuum states [4]. Therefore it produces enormous atomic and nuclear data which should be interpreted for understanding the weak transitions rarely measured by other spectroscopic techniques [5–9]. With the development of much faster heavier beams, ion-atom collision spectroscopy proves to be a milestone in confirming the theoretical transition energies, oscillator strengths and other parameters calculated by various theoretical models or spectroscopic codes [10,11]. After many decades of beam-foil spectroscopy many gaps still exist in the identification of many transitions that are not yet observed or difficult to observe. However, they have been predicted theoretically or observed in systems other than beam-foil [12–16], whereas some others have been claimed to be observed indirectly from delayed observation of X-rays [15,16].

To observe such low cross section transitions and all the components of any cascade at the same time we have developed a multipurpose facility that covers the spectroscopic region from intense X-rays to Near infrared (0.1–10,000 Å). While the old set-up was able to be used with a beam-foil set-up only; the new system can be used for the study of beam-foil, beam-gas and plasma spectroscopy. The collection efficiency is also enhanced by 100 times from our previous setup. The grating spectrometers are very sensitive to minute vibrations therefore optical alignment of a spectrometer is the most challenging task during the development of the complete BFS set-up. So, the detailed optical alignment of spectrometer is discussed to put more emphasis and understanding on it and its related configurations.

2. Instrumentation: implementation and function

2.1. Limitations of the existing setup

The existing setup at the Inter University Accelerator Centre (IUAC), New Delhi, India can only be used with beam foil spectroscopy covering the X-ray regime from 1 keV onwards. On the other hand the 300 mm diameter size of the chamber, although

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not very large still restricts the closeness of the detectors to the interaction region. This distance is good enough for the strong reactions but still reduces the solid angle for the detectors by 100 times from what it is near the interaction region. The loss in the solid angle and hence the collection efficiency of the detector leads to the inaccessibility to low intensity processes. This existing facility cannot be used to study the beam gas collisional spectroscopy and plasma spectroscopy. Apart from the mentioned limitations of the existing facility, it does not cover the visible region that is the crucial region to study lighter elements and high Rydberg states. To overcome all the above mentioned limitations, we developed a new facility that can be inserted just after the existing facility without disturbing it.

2.2. Development of the multipurpose facility for spectroscopic studies

For doing the multipurpose spectroscopic study for various atomic systems, an unorthodox multipurpose chamber is fabricated to attach the Spectrometer as shown in the Fig. 1. The vertical diameter of the chamber is 160 mm and its thickness is only 24 mm, intentionally to minimize the distance of the interaction region from the entrance slit of the spectrometer and opposing X-ray detector. A vacuum of 10^{-5} torr can be created in the chamber within less than 4 min, provided the spectrometer body is already at a high vacuum of 10^{-6} torr, by opening the valve between them. Four sides of the chamber are provided with 16KF couplings for the effortless connections of the various components with the chamber. A 2.75CF adapter is provided on the other side of the chamber for collecting X-rays simultaneously. This side of the chamber can also be used for calibration during the experiment using a calibration lamp, X-ray detector, as a viewport or to introduce discharge electrode to produce gas plasma as shown in Fig. 2(a). Provision of various collimator sizes is also present in the chamber to control the photon counts or to change the ion beam path observable to the detector. The Chamber itself acts as an adapter for the spectrometer and can be used as a spectroscopic plasma device also to generate plasma using beam gas collisions or using discharge for the spectroscopic purpose. For the use of beam gas spectroscopy or a discharge plasma source, the chamber is provided with a continuous gas jet assembly and differential pumping. This differential pumping solves two purposes: firstly it maintains a precise and accurate pressure inside the chamber for discharge plasma or beam-gas collisions and secondly it reduces the gas flow toward the spectrometer. Apart from differential pumping, a rectangular secondary slit is deliberately made in the chamber facing the actual entrance slit. This combination of differential pumping and the set of two slits minimizes the gas flow from the chamber to the spectrometer and therefore enables one to observe transition wavelengths below 2000 Å without their absorption. A charge coupled device (CCD) based detection system that can be replaced by photo multiplier tube (PMT) is installed in the facility. We have optimized the system for performing the low cross sections measurements with the modified BFS set-up.

2.3. Spectrometer

2.3.1. Optical alignment

As the existing set-up was not aligned for precise optical measurements, corrective measures were done to align the system. Here we report the alignment of the spectrometer where the

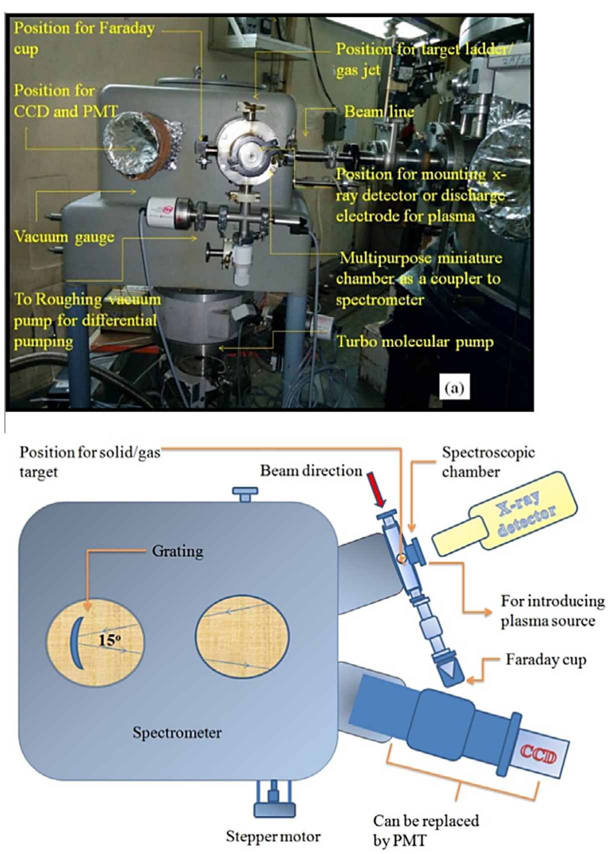

Fig. 1. Experimental set-up showing the various components of the facility: (a) Actual picture and (b) schematic of the facility (top view).

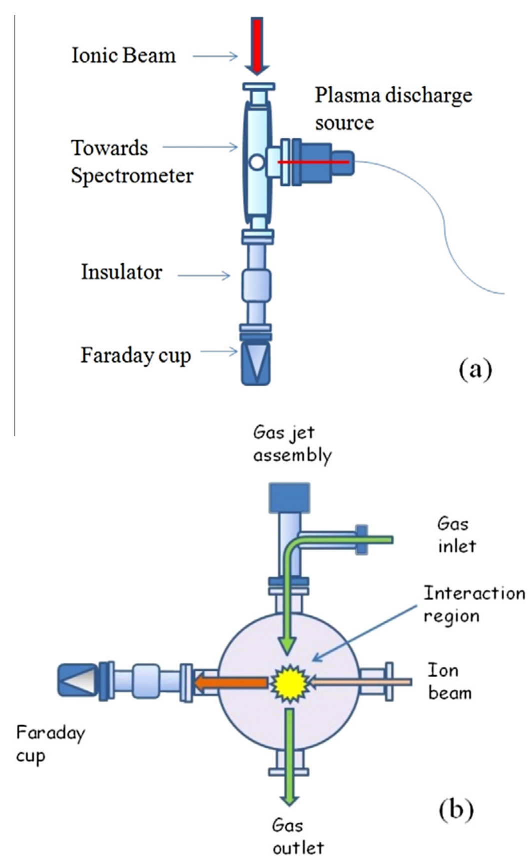

Fig. 2. Experimental chamber design (a) Top view of the chamber, (b) front view of the chamber is shows with the beam-gas collision setup used with differential pumping.