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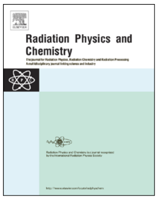

An apparatus to study the energy and angular distributions of electron-bremsstrahlung photons from gaseous targets

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HIGHLIGHTS

- Experimental setup is developed to study DDCS of electron-bremsstrahlung from gaseous targets.
- TTB from scattering chamber's wall is reduced appreciably by using a teflon cylinder.
- Shape of DDCS of bremsstrahlung compared with the theories shows a satisfactory match.
- Angular distributions of bremsstrahlung show anisotropy but still affected by TTB background photons.

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ABSTRACT

An apparatus is developed to measure the energy- and angular distributions of bremsstrahlung generated from collisions of energetic electrons with isolated atoms and molecules. A considerable reduction of thick target bremsstrahlung (TTB) background produced by scattered electrons from the chamber wall is achieved. Details of the experimental setup with regard to design of its components, experimental technique, data acquisition and analysis etc. are given and discussed. The reliability and performance of the setup are demonstrated by obtaining some test results on angular- and energy distributions of bremsstrahlung produced in collisions of 4.0 keV electrons with free argon atoms. These results are compared with the theoretical predictions of the *ordinary*- and the *polarization* bremsstrahlung emissions. In this comparison, the experimental data for energy distributions of BS photons are found to be in reasonable agreement while they are found to have noticeable differences in shape of angular distributions.

1. Introduction

Bremsstrahlung (BS) is a fundamental process of emission of radiation in interaction of an energetic electron with an atom/ molecule. In earlier days, starting from the discovery of X-rays till 70's, it was understood that BS is produced when an energetic charged particle scatters-off in the static field of nucleus of an atom; such type of radiation was named as *ordinary bremsstrahlung* (OBS). But, thereafter, another mechanism was proposed theoretically by Buimistrov and Trakhtenberg (1975) in which it was suggested that a dipole is induced in an atom as a result of repulsion felt by atomic electrons due to the field of energetic projectile electron. The relaxation of the induced atomic dipole moment results in emission of photons lying in the region of X-rays; such type of radiation was named as *polarization bremsstrahlung* (PBS). Several experimental and theoretical studies have been made on determination of BS cross sections in the frame of OBS from gaseous atoms/molecules by electron impact (Hippler et al., 1981; Quarles and Heroy, 1981; Semaan and Quarles, 1981, 1982; Hippler et al., 1982; Kissel et al., 1983; Tseng and Pratt, 1971; Tseng et al., 1979). A benchmark work on theoretical side of OBS calculated in relativistic partial wave Born approximation is available in tabular form by Kissel et al. (1983). In several experiments, the study is limited to the comparison of the cross section measurements with the theory of OBS. Several reviews on PBS are available (Korol et al., 2002a; Korol et al., 2001; Korol and Solov'yov, 1997). The best calculations of PBS have been in the case of radiation in the vicinity of inner shell resonances. For quite a while it was generally believed that PBS would not be important for radiated photon energies well away from such atomic resonant energies. However, it was realized later that PBS could contribute at any photon energy and with the effort of Solov'yov and his colleagues, the contribution of PBS was calculated for several specific cases. Of particular interest is the

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case of Ne and Ar for impact of 1–25 keV electrons (Korol et al., 1997). Quite a few experimental studies have looked for a PBS contribution to the doubly differential cross section (DDCS) for incident electron energies in the range of 25–100 keV from thin films of various atomic numbers; a useful review on this topic can be found by Quarles and Portillo (2006). In summary, OBS was found to fit the energy dependence of the radiated photon spectrum very well which strongly suggested that there is a negligible contribution of PBS over OBS in such cases. This conclusion was further corroborated by studies of thick target BS and by comparison of the observed yields with predictions of the sophisticated Monte Carlo code PENELOPE (Salvat et al., 2006). The latter code employs the OBS cross sections obtained from the tabulations of Kissel et al. (1983). The search for PBS contribution to the thick target yields was made and expected especially to be present at lower energy of radiated photons. However, no evidence for a PBS contribution was established and the data were found to be in good agreement with the PENELOPE calculations. The only case where a definite signature of PBS contribution has been observed is the *absolute* measurements of DDCS of BS from collisions of 28 keV and 50 keV electrons with Ne, Ar, Kr and Xe gaseous atoms by Portillo and Quarles (2003). They found a significant enhancement over the prediction of OBS. While there was a good agreement with the magnitude of the stripping approximation (SA) calculations for 28 keV and 50 keV electron impacts on Kr and Xe, there was no evidence for the discontinuities near the absorption edges predicted by SA. The experimental results for Ar were significantly higher than those of SA predictions.

Extensive literature survey reveals that angular measurements of BS, till date, have been made mostly for thick targets and thin foils (Requena et al., 2011; Ambrose et al., 1991; Requena et al., 2010). Such studies are, however, scarce for isolated atoms and molecules. To the best of author's knowledge, the only study on the angular distributions of BS produced near the considered energy has been made for inert gases (Ar, Kr, Xe) under 3–15 keV electron impact by Aydinol et al. (1980). In this study, the observed anisotropy of the BS is explained by modified Sommerfeld formula.

In order to see the contribution of PBS and to measure the angular distributions of BS, the main challenge is to get rid of various sources of background radiations. A simple approximate model for the TTB background is given by Haygood et al. (2006). BS has a wide practical interest and importance in variety of fields from viewpoint of applications, such as, astrophysics, atmospheric physics, radiation physics, fusion plasma and several other areas, where the knowledge of BS emission cross sections, its energy-and angular distributions is required for diagnostic purposes.

In view of the above status, the present work describes the development of a new experimental setup that facilitates the reduction of background radiation to an appreciable extent. Such an apparatus has been used to measure the energy- and angular distributions of BS produced from free atoms and molecules in collisions with energetic electrons. Reliability and functioning of the developed setup is demonstrated by measuring the angular- and the photon energy distributions of BS spectra produced from isolated argon atoms by impact of 4.0 keV electrons. The considered energy range of BS lies between 2.4 keV and 3.8 keV, while the angular range is covered from 45° to 120° at an interval of 15°.

2. Experimental setup and measurement procedures

The schematic diagram of the developed apparatus is shown in Fig. 1. The main components of the setup are discussed in the following sections:

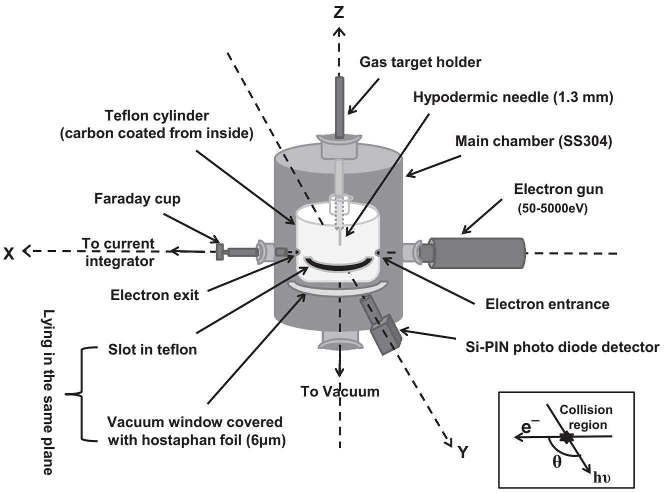

Fig. 1. Schematic of the experimental setup with different components marked in the figure. *X*-, *Y*- and *Z*- axes show the directions of electron beam, photons detection and gas flow respectively. Inset shows the detection angle θ for emitted photons with respect to the electron beam.

2.1. *The scattering chamber*

The experimental setup involves a SS304 stainless steel cylindrical chamber of 82 mm diameter, 3 mm thickness and 200 mm height. It is pumped down by a 150 l/s oil diffusion pump (M/s Hind High Vacuum Co. Ltd., India) backed by a rotary pump (30 m^3/h). The pressure of the chamber is monitored by an ionization pressure gauge (PKR 251, Pfeiffer Vacuum, Germany). The base pressure attained in the chamber without gas load is $\sim 8\times10^{-7}$ Torr. Two KF10 ports opposite to each other are available on the scattering chamber for mounting the electron gun and the Faraday cup respectively. For X-ray detection, there are two 5 mm wide slots available around the chamber situated symmetrically on either side of the chamber in a horizontal plane (see Fig. 1). These slots are covered with 6 μm hostaphan foils, which serve the purpose of a window to transmit the photons produced in the main chamber up to the detector as well as to hold the vacuum of the collision chamber. A gas target holder, movable in *Z*-direction, is inserted inside the chamber through the center of the top flange of the chamber via vacuum feed through system. The bottom end of the holder is attached with a hypodermic needle. The position of the hypodermic needle inside the chamber can be fixed to a desired height without exposing the chamber to atmosphere.

2.2. *Gas handling system*

The argon gas is injected into the chamber through a hypodermic needle ($\Phi = 1.3$ mm and length$=20$ mm) whose tip is kept about 2 mm above the electron beam level during the experiment. The effusing gas beam intersects the electron beam at 90°. No attempt is made to determine the density of the gas on an absolute scale in the present experiment. During experiment, the pressure of the chamber with gas load is kept around 3×10^{-4} Torr ensuring a single collision condition which was established through an auxiliary experiment.

2.3. *The electron source*

The continuous electron beam is obtained from an electron gun (ELS5000, M/s PSP Vacuum Technology, UK). The energy of the electron beam can be varied between 50 eV and 5000 eV. The gun is μ-metal shielded. The electron beam is guided and derived