Calcium projectile ion radiation dynamics in gaseous target.

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Experimental investigations of the slowing-down process of calcium projectile ions traveling through the neon gas were carried out at the UNILAC facility at GSI in the frame of the project U-189 "X-ray spectroscopy of projectile ion and target radiation". The main goal was to demonstrate the influence of the target density on the charge state distribution inside matter. In order to analyze the projectile charge state distribution along the trajectory the X-ray spectroscopy of projectile ion *K-shell* radiation was applied. Ca projectile ion spectra were measured with high spectral ($\lambda/\delta\lambda$=3000) and spatial resolution (100μ) along the ion beam stopping path. The dependence of the characteristic ion spectrum on the ion beam penetration depth in the gaseous target was investigated.

The $48Ca^{+10}$ ion beam with initial energies of 5.9 and 11.4 MeV/u was delivered to the target chamber at Z6 experimental area. The ion beam was well collimated by means of two 2mm carbon apertures. The typical pulsed ion beam current in gas was 0.1-0.2 µA. The macro pulse duration was 5 - 5.5ms with a frequency of 2-5 Hz. The gas target was designed as a cylindrical copper box with a length of 210 and an inner diameter of 30mm filled with Ne gas under 1.9 bar pressure. The target was separated from 10^{-5} mbar vacuum in the experimental chamber by 5µm entrance Havar foil. The gas flow in the tube served for the renewal of the stopping medium. Three rectangular windows 4mm x 40mm used for X-ray diagnostic were oriented along the direction of the ion beam propagation. The distance between the entrance hole and the beginning of the first diagnostic window was 20 mm. The windows were covered with a 5µm Ti foils transmitting 60% of 3-4 keV photons and effectively protecting the crystal spectrometer from parasitic low energy radiation.

After passing through the entrance Havar foil, the $48Ca^{+10}$ ion beam enters the gas having an equilibrium charge state distribution. From the first diagnostic window we observed *K-shell* Ca radiation dynamics along 40mm of the ion stopping path. Spectra were measured by mean of Focusing Spectrometer with Spatial Resolution [1]. The mica spherically bend crystal was used as a dispersive element. An X-ray Kodak Direct Exposure Film (DEF) was exposed 10-12 hours.

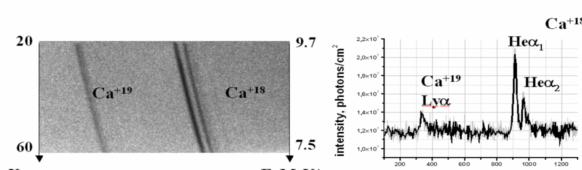

Fig.1. Radiation dynamics of Ca projectile ions with initial energy of 11.4 MeV/u slowed down in 1.9 bar Ne-gas. X, mm – penetration depth, measured from the entrance foil

The spectrum in Fig.1 shows radiation of Ca^{+19} and Ca^{+18} ions in 9.7-7.2 MeV/u energy region. We observe Lyα (1s-2p), Heα_1 ($1s^2$-1s2p $^1P_1$) and Heα_2 ($1s^2$-1s2p $^3P_1$) radiative transitions. Characteristic feature of the spatially resolved along the ion penetration depth spectrum is the tilted form of lines. Measured characteristic lines are shifted in wavelength due to the Doppler Effect. This shift depends on the projectile velocity and the observation angle. In the experiment the spectra were observed at the angle providing the shift to the higher photon energies - "blue" shift. Due to the ion energy loss in stopping media the line Doppler shift is decreasing continuously with the ion penetration depth, lines become tilted. This fact was used to determine projectile ion velocity depending on the penetration depth in stopping media [2, 3, 4].

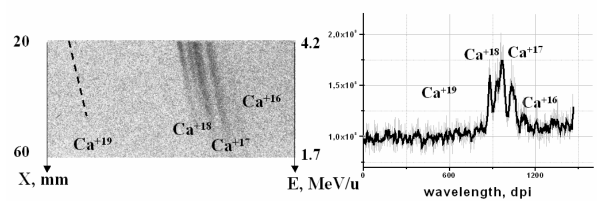

Fig.2. Radiation dynamics of Ca projectile ions with initial energy of 5.9 MeV/u slowed down in 1.9 bar Ne-gas

Fig.2 presents a *K-shell* spectrum of Ca ion beam at lower energies of 4.7 – 2.1 MeV/u. At these energies the radiation of Ca^{+19} (Lyα) ions is fully absent and the maximum of the spectra line intensity is shifted to the group of satellites originating from the autoionizing states of Ca^{+17} and Ca^{+16}. This shift to the lower charge states is due to the increase of the bound electron capture cross sections at lower projectile energies.

Spatially resolved *K-shell* spectra of Ca ions with initial energy of 11.4 MeV/u slowed down in solid and porous stopping media [3, 4] differ from those obtained in experiments with gaseous targets. In solid matter we observe long lasting intense radiation of highly charged ions Ca^{+19} and Ca^{+18} down to the energies of 2.5 - 3 MeV/u.

The "gas-solid" difference in projectile charge state distribution we attribute to the increase of the effective ionisation cross sections and suppression of the bound electron capture in dense stopping media [5]. Both processes tend to the increase of the projectile ion charge in dense matter.

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