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On the absorber thickness of microcalorimetric detectors in experiments at nuclear storage rings

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The precise determination of the 1s Lamb Shift in hydrogen-like very heavy ions provides a sensitive test of quantum electrodynamics in very strong Coulomb fields. The Lyman-a transitions of high-Z ions, which include the Lamb shift, have energies in the range 50-100 keV. To increase the accuracy of the measurements, microcalorimeters for hard X-rays are successfully used because they combine excellent energy resolution with an acceptable detection efficiency [1, 2].

Experiments with heavy hydrogen-like ions are performed at nuclear storage rings in conditions when the x-ray lines have a significant Doppler shift. The finite size of the X-ray emitting interaction region of ion beam and gas-jet leads to an additional contribution in the line width of the detected Lyman X-ray lines, namely the so called Doppler broadening. Under typical experimental conditions, Doppler broadening may be much greater than self width of the detector line w_s.

The accuracy of the energy of the Lyman X-ray lines is determined by three factors: the accuracy in determining the position of the peak in the spectrum, the error in the energy calibration of the detectors, and the accuracy in the Doppler correction. The latter two factors can be minimized by appropriate organization of the experiment. The accuracy of the peak position ΔE_{Lab} is eventually determined by the line width w_{Ly} and the number of the recorded photons N.

$$\Delta E_{Lab} = w_{Ly}/(2.35 * N^{0.5}) \qquad (1)$$

The line width w_{Ly} and the number of photons N depend on the thickness of the absorber d of a calorimetric detector. The width of the Lyman line wLy has two contributions: the self (or lab) width ws and Doppler broadening w_D:

$w_{Ly} = (w_s^2+w_D^2)^{0.5}$. If the electronic baseline noise is the main contribution to the self width ws , the self width does not depend on the photon energy and is proportional to the thickness of the absorber d.

The number of recorded quanta N depends on the absorber thickness in the usual manner:

$N = N_0*k*(1\text{-}\exp(-\mu d))$. Here N0 is number of Lyman X-ray quanta that fall on the absorber; μ is X-ray absorption coefficient. The coefficient k gives the fraction of absorbed photons, which will release all the energy in the absorber. Factor k can be significantly less than unity in the case of the formation of so-called escape peak.

The optimum thickness of the absorber is determined by the minimum of the expression (1) taking into account all the factors mentioned above. In this report, we introduce our optimization procedure as a function of absorber thickness for the two materials: tin and lead. In particular, we discuss the mutual interference of the self line width ws, Doppler broadening wD and the absorption efficiency taking into account possibilities of the escape of secondary radiation.

1. V.A. Andrianov et al., Journal of Low Temperature Physics 151 (2008) 1049
2. S. Kraft-Bermuth et al., Journal of Low Temperature Physics 167 (2012) 765