Electron detachment spectroscopy on a fast ion beam using a magnetic bottle.

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Electron spectroscopy on a fast ion beam inevitably leads to a kinematical broadening of the electron energy spectra. Earlier this has been seen as a problem since it degrades the electron energy resolution [1]. Here we show that the situation can be advantageous as a proper analysis of the emerging line shapes still allows to extract the rest-frame electron energy. Moreover it yields the angular distribution parameter $\beta$ of the emitted electron.

Two approaches to use the broadening effect

Analytical approach

By combining the expected kinematic broadening with the $\beta$ – parameter dependent formulation of the distribution of emission angles one can calculate the expected time of flight distribution of the electrons:

Eq 2: $t = \frac{1}{v_e} \sqrt{\frac{l^2}{v^2_e} + \frac{L^2}{v^2_e \cos \beta}}$  

Eq 3: $P(\theta, \beta)(\cos \theta) = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}\frac{L^2}{v^2_e \cos \beta \cos \theta}ight)$  

Eq 4: $P(\theta, \beta)(\cos \theta) d\theta = \frac{1}{\sqrt{2\pi}} \exp\left(-\frac{1}{2}\frac{L^2}{v^2_e \cos \beta \cos \theta}ight) \frac{\cos \theta}{\cos \beta} d\theta$

The time of flight distribution of photoelectrons (Eq 4) can be derived by combining Eq 2 and 3. Eq 2 describes the time of flight of an electron vs. the emission angle relative to the moving ion beam. Eq 3 gives the distribution of the emission angles of the photoelectron. $L$ denotes the length of the drift tube, $\beta = \{1.2\}$ is the anisotropy parameter, and $\theta$ is the emission angle towards the ion beam [2].

In the analytical approach it is assumed that the electrons are bent towards the detector instantaneously. The ray tracing approach mostly suffers from the approximate calculation of the magnetic field:

Fig. 1: The dependence of the effective electron velocity $v_e$ on the ion-beam velocity, the electron velocity in a resting reference frame and the emission angle.

Simulation / ray tracing

A ray trace simulation which takes the magnetic field into consideration can reproduce the expected time of flight distribution. Eq 1 and Eq 3 are used for the electron start conditions.

Domesle et al. [2] successfully expand the analytical approach using a parametric Monte Carlo simulation (Fig. 4a). We successfully used the ray tracing method to determine the beta parameter of the detachment process of OH - (Fig. 4b).

Fig. 3: Electron time of flight distributions for different electron energies and anisotropy parameters calculated using Eq 3 (dotted lines) and simulated using Simion (solid lines). The kinetic energy of the ions was 4.8 keV.

Fig. 4 a): Electron t.o.f. distribution after photodetachment of O at 266 nm. The red curve is the measured spectrum, grey and black show the calculated ones. From [2].

And b): Electron t.o.f. distribution after photodetachment of OH, where the black curve shows the measurement and the red curve the simulation.

References: