Precise measurement of collision-induced atomic alignment and magnetic sub-state ionization

Xing Wang*, Zhongfeng Xu

Xi'an Jiaotong University, Xi'an 710049, China

Atomic alignment

Theoretically usually calculated using plane-wave Born approximation theory (PWBA) and Semi-classical approximation theory (SCA)

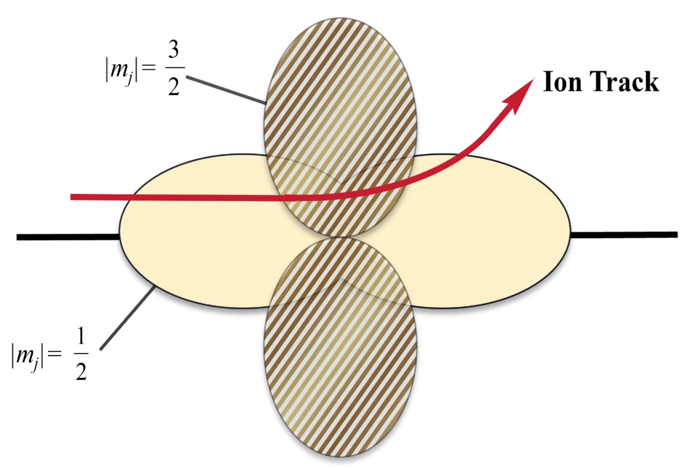
L_3-subshell (j = 3/2)，alignment parameter A_{20} :

$$A_{20} = \frac{\sigma_{3/2} - \sigma_{1/2}}{\sigma_{3/2} + \sigma_{1/2}}$$

Experimentally by measuring the spatial distribution of the characteristic X-ray radiation and the polarization of the Auger electron.

$$\beta = \alpha \kappa A_{20}$$

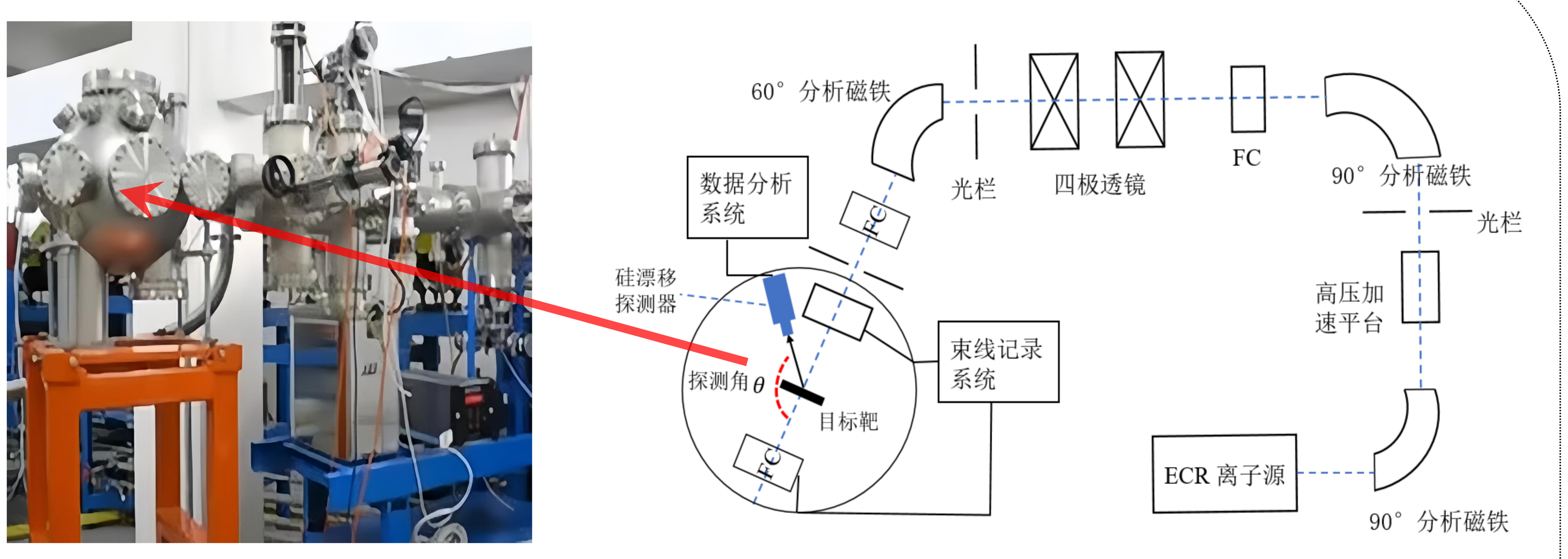
- κ : C-K transition coefficient
- α: Anisotropic parameter coefficient
- β : Anisotropy parameter



Definition of the alignment properties of the L_3-subshell

The magnetic sub-state ionization cross-sections, $\sigma_{3/2}$ and $\sigma_{1/2}$, are derived by combining the ionization cross-section, σ_{L3} from equation of A_{20} with the experimentally measured A_{20}.

Experimental methods

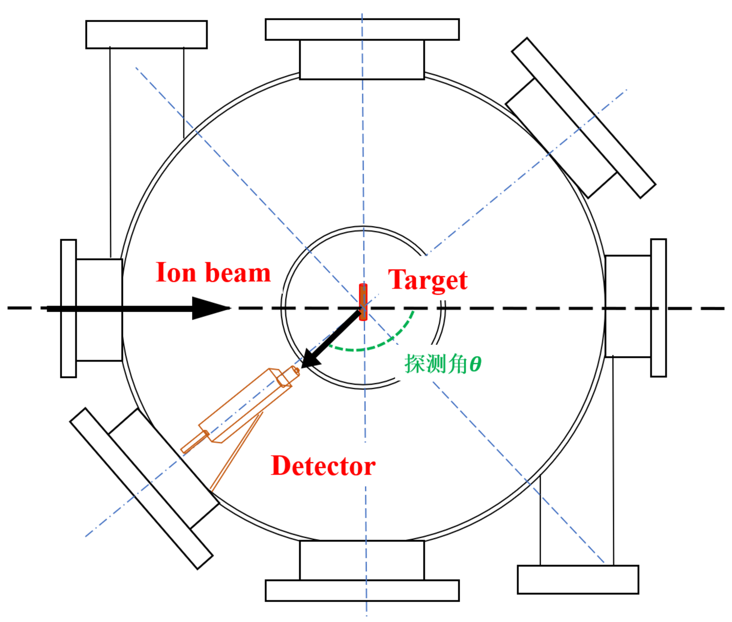


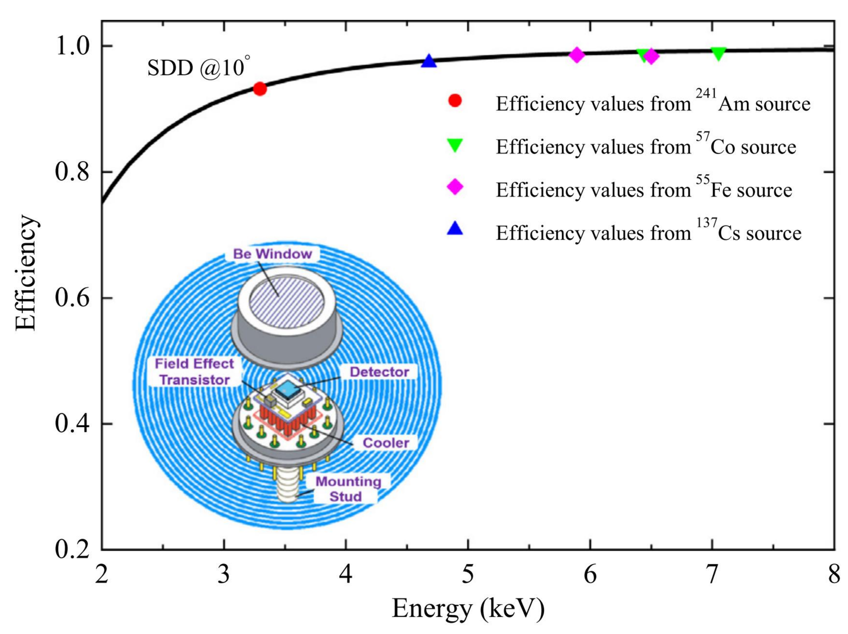
Schematic diagram of the experimental terminal

① Use different particle-atom collisions to achieve accurate measurement of the spatial distribution of the characteristic radiation.

② Analysis of the alignment parameter at different approximate velocities based on the spatial distribution of the characteristic radiation intensity, and comparative study of the alignment properties of L_3 under different collision systems.

③ The relevant theoretical model of ionization is modified.





Data processing

Determination of alignment parameter based on X-ray differential intensity ratios:

Determination of the $L_{\beta 2}$-line anisotropy parameter β:

$L_{\beta 1}$: $2p_{1/2}$=（j=1/2）subshell

Isotropic emission

Employed as good reference line to remove geometric bias and incident ion numbers

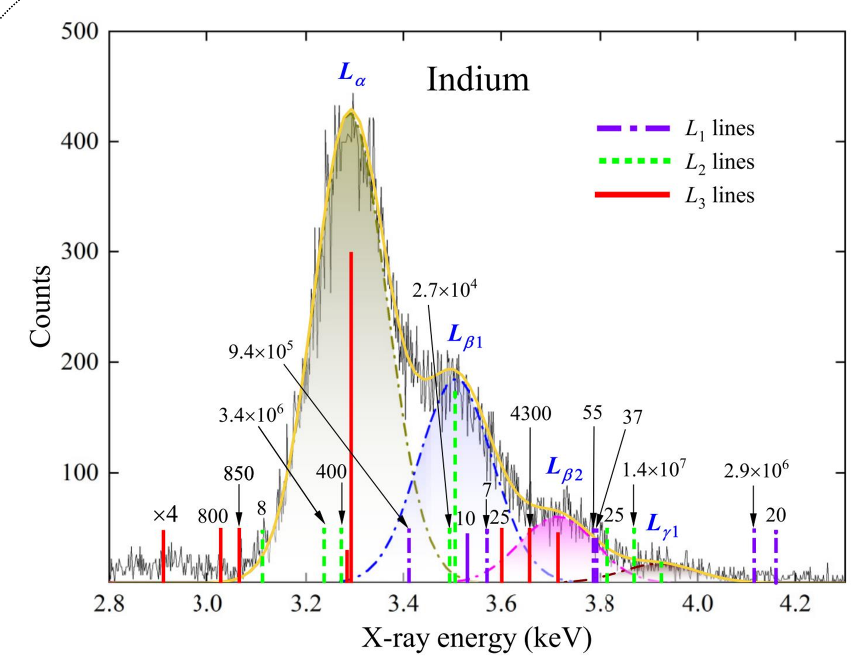
Theoretically:

$$\frac{dI}{d\Omega} = \frac{I_0}{4\pi}(1 + \beta P_2(\cos\theta))$$

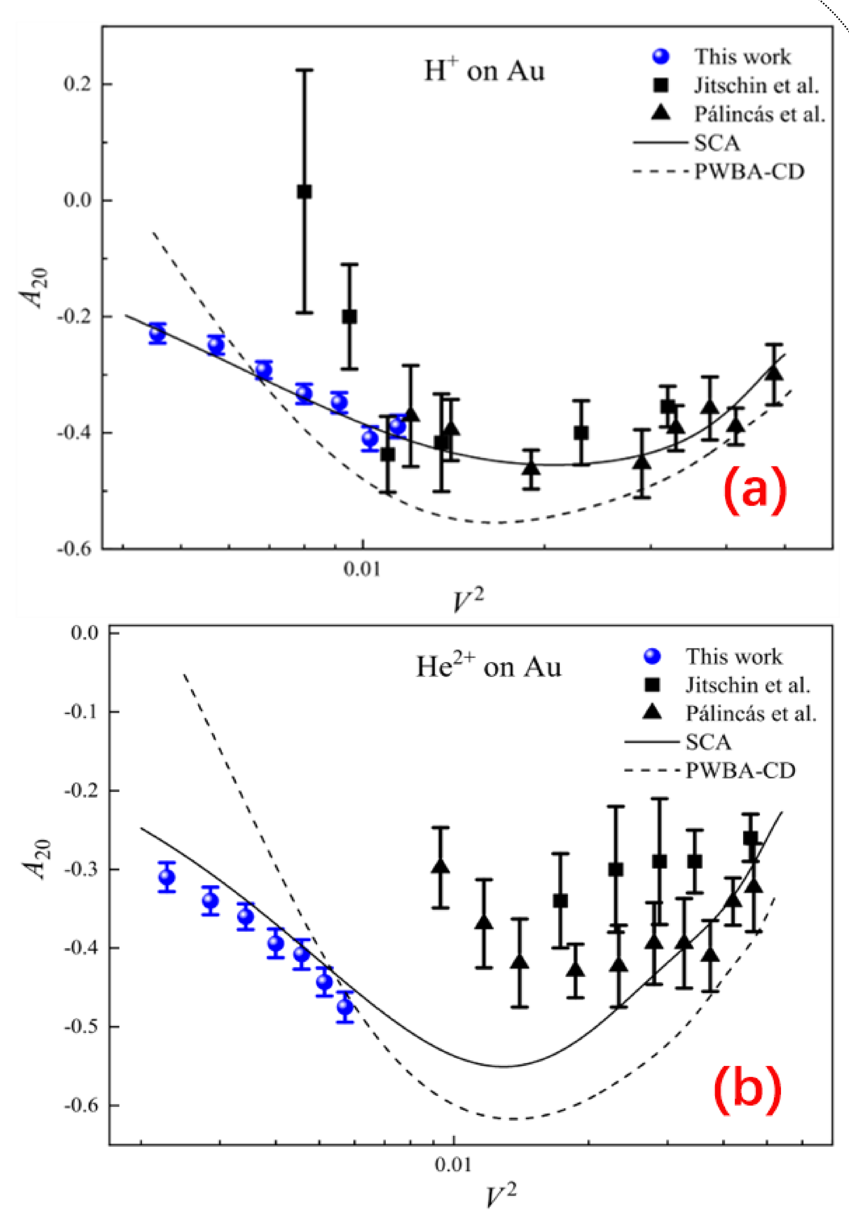
Experimentally:

$$\frac{dI(L_i,\theta)}{dI(L_{\beta 1},\theta)} = \frac{N(L_i)\varepsilon(L_{\beta 1})}{N(L_{\beta 1})\varepsilon(L_i)} = a_i + b_i P_2(\cos\theta) = a_i[1 + P_2(\cos\theta)]$$

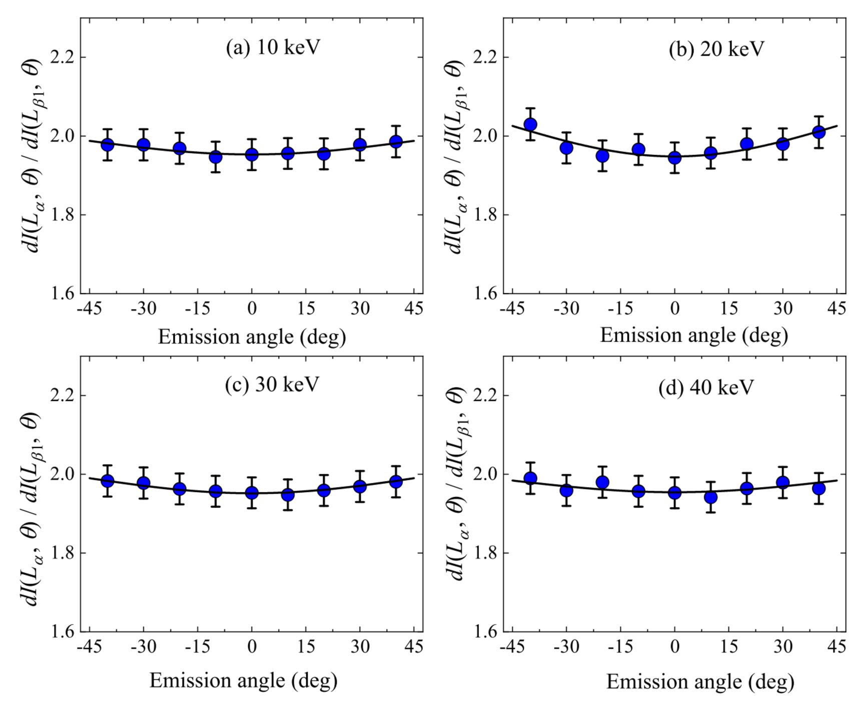
Results and discussion



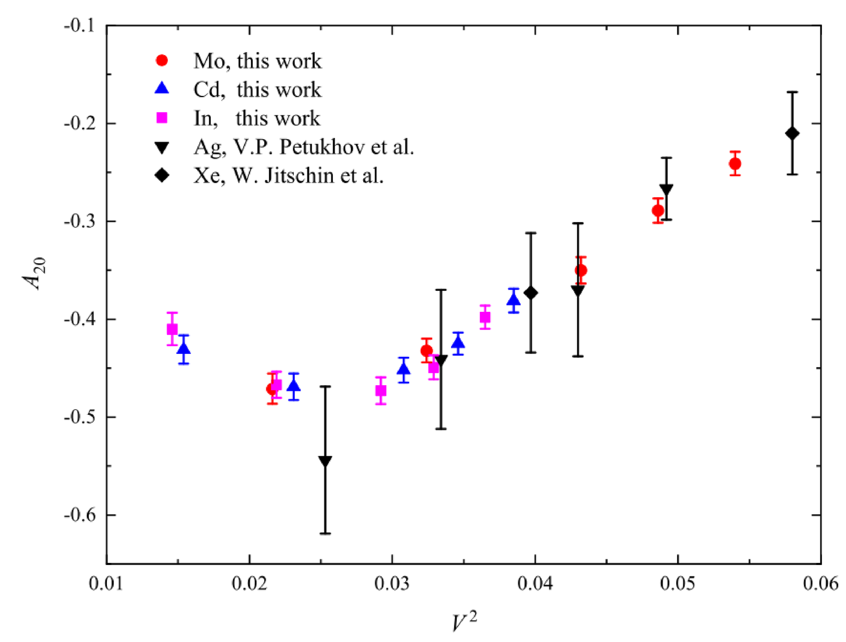
Measured typical spectra for In by proton impact



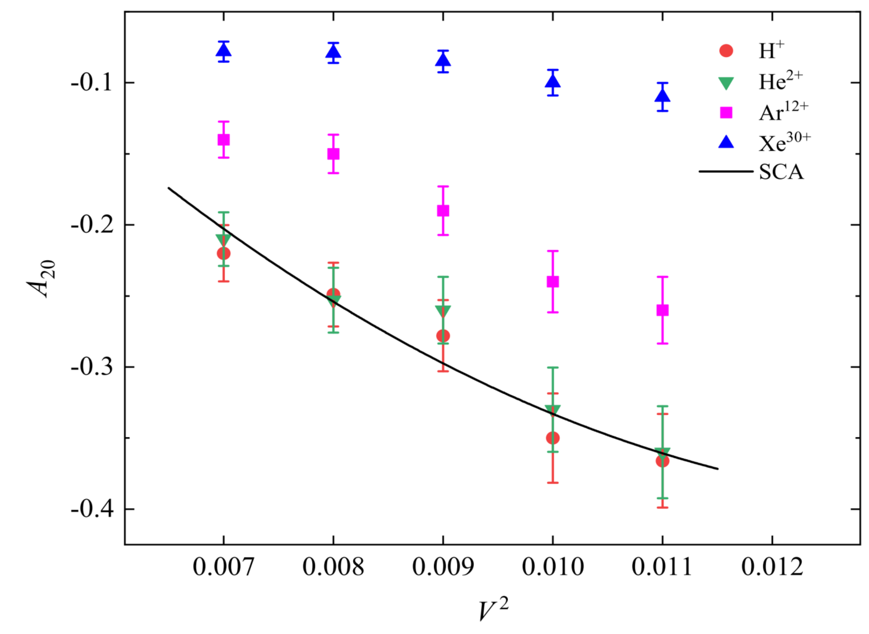
Alignment parameters A_{20} of Au as a function of the square of scaled projectile velocity V^2 of protons (a) and He^{2+} (b).



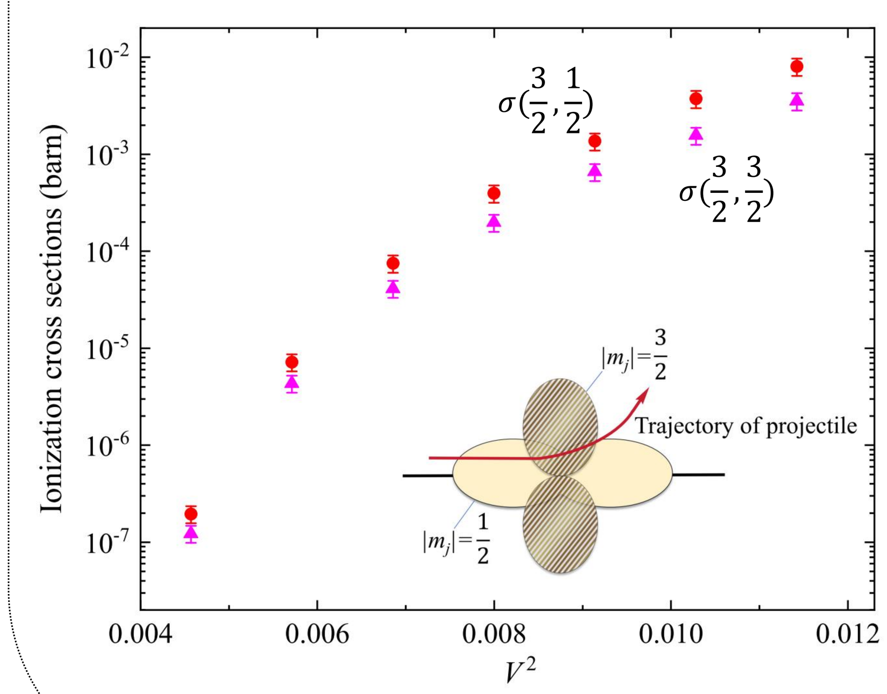
Differential intensity ratio as a function of emission angle



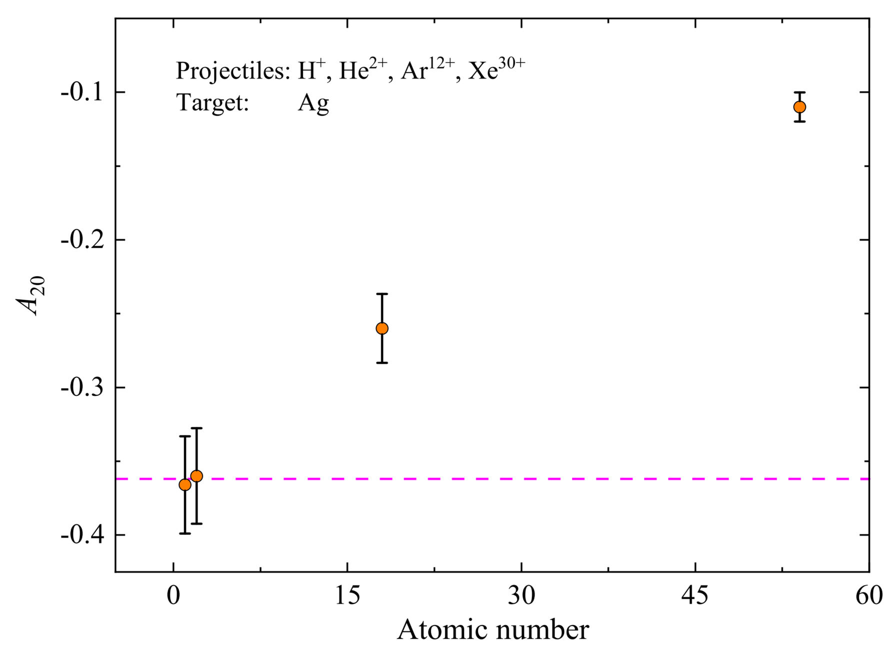
Proton-impact-induced alignment of medium-Z_t elements



Alignment parameter A_{20} of Ag as a function of the square of scaled projectile velocity V.



Magnetic sub-state ionization cross sections



Alignment parameter A_{20} is shown as a function of atomic number at V^2 = 0.011. Ag target is bombarded by 0.067 MeV $^{1}_{1}H^{+}$, 0.268 MeV, $^{4}_{2}He^{2+}$, 2.680MeV $^{40}_{18}Ar^{12+}$ and 8.643 MeV $^{129}_{54}Xe^{30+}$ ions, respectively.

Conclusion

❶ The relationship between alignment parameter A_{20} and the incident energy of different collision systems (electron and ion) is investigated experimentally.

❷ Perturbation of multi-ionization on atomic alignment properties can effectively predict numerical values and trends of experimental results.

❸ Magnetic sub-state ionization cross-sections （$\sigma_{3/2}$ and $\sigma_{1/2}$） in low incident velocity are explored.

References

[1] S. Flügge, W. Mehlhorn et al., *Phys. Rev. Lett.* 29 (**1972**) 7

[2] N. B. Clayburn and T. J. Gay, *Phys. Rev. Lett.* 119 (**2017**) 093401

[3] X. Wang, X. Liu et al., *Physical Review A* 105 (**2022**) 052807

[4] X. Wang, Y. Liu et al., *Results in Physics* 44 (**2023**) 106196

[5] X. Wang, Y. Liu et al., *Physics Letters A* 512 (**2024**) 129587

Email: wangxingcn@xjtu.edu.cn