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Target ionization and projectile electron loss in simple collision systems (*)

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Résumé. — Nous avons mesuré les sections efficaces absolues doublement différentielles pour l'ionisation de la cible et la perte d'électrons du projectile, lors de collisions de H^+ , H_2^+ , $^3He^+$ et $^3He^{++}$ (0,4 à 2,0 MeV/u) contre He et Ar, à des angles d'émission des électrons compris entre 0° et 60° . Les résultats expérimentaux sont qualitativement bien décrits par l'approximation de l'onde plane de Born en tenant compte des effets de blindage du projectile.

Abstract. — Absolute double differential cross sections for target ionization and projectile electron loss were measured in collisions of H^+ , H_2^+ , $^3He^+$ and $^3He^{++}$ (0.4 to 2.0 MeV/u) with He and Ar at electron emission angles from 0° up to 60° . The experimental results are qualitatively well described by plane wave Born approximations including projectile screening.

Electron spectra from ion-atom collisions observed near 0° with respect to the beam direction exhibit a sharp cusp-shaped peak centred at an electron velocity v_e matching the velocity of the incident projectile v_p (see e.g. [1] and refs. therein). In the case of bare ions this peak is due to capture of a bound target electron into a continuum state of the projectile ion (ECC). For incident ions with bound electrons this peak is mainly due to projectile electron loss from bound to continuum states of the projectile (ELC). If the incident projectile carries bound electrons into the collision the target ionization can be influenced by two further processes [2, 3] :

(1) the electrons may screen the projectile nuclear charge thus weakening the interaction potential,

(2) the projectile ion can be excited simultaneously with target ionization by interactions between electrons from target and projectile.

Therefore, the cross sections for target ionization may be decreased or increased relative to the same but bare projectile ion (cf. [4] and refs. therein). For projectile ionization (ELC) [5] the effects (1) and (2) are expected to be even stronger because the neutral target atom (the ionizing particle

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in this case) carries all its electrons. Thus, in ion-atom collisions with structured projectile ions such phenomena can be studied twice in one electron spectrum, i.e. in the target and in the projectile ionization [6, 7].

We have measured absolute double differential cross sections (DDCS) $d\sigma/(d\Omega \cdot dE)$ at electron emission angles θ_{lab} from 0° up to 60° for collisions of H^+ , H_2^+ (0.4, 0.8, 1.1, 1.7, 2.0 MeV/u), $^3He^+$ (0.8, 1.7, 2.0 MeV/u), and $^3He^{++}$ (2.0 MeV/u) with He, and collisions of H^+ , H_2^+ (1.1 MeV/u) with Ar. At a fixed electron emission angle $\theta_{lab} = 40^\circ$ (and partly 47°) we have also measured DDCS for collisions of H^+ , H_2^+ (0.4, 0.6, 0.8, 1.2, 1.7, 2.0 MeV/u) and $^3He^+$ (1.7 MeV/u) with Ar. The measurements were performed at the Frankfurt University Van de Graaff accelerators. With a dynamic gas target the spectra were recorded under single-collision conditions with a magnetic electron momentum analyser [8] (momentum resolution $\Delta p/p = 5\%$, acceptance $\Delta\theta = \pm 7^\circ$). The measured relative DDCS (with an electron energy range from 20 eV up to 7 000 eV) were made absolute by normalizing the data to absolute DDCS measured for H^+ -He and H^+ -Ar collisions [9]. Details of the measurements and the data reduction will be published elsewhere [10].

The theoretical calculations for target and projectile ionization were carried out in the plane-wave Born approximation (PWBA) including screening and excitation of the ionizing particle, i.e. projectile and target, respectively (see [11] and refs. therein). In the ELC calculations the screening could be taken into account also by representing the target nucleus by a Thomas-Fermi potential [5].

At set of typical spectra measured in $^3He^+$, H_2^+ , and H^+ collisions with He at 0.8 MeV/u projectile energy and various emission angles θ_{lab} is presented in figure 1. Features common to all spectra are the large contribution of low-energy electrons from the target continuously decreasing in intensity with increasing electron energy, and the binary encounter peak shifting to lower electron energies with increasing angle. For proton impact the ECC-peak occurs which disappears at angles $\theta_{lab} \neq 0^\circ$, while for incident $^3He^+$ and H_2^+ ions, respectively, a considerable contribution of ELC-electrons can be observed with the peak shape and intensity changing with the electron emission angle.

To study the projectile screening the electron spectra measured for the different projectiles (with nuclear charge Z_p) were divided by that for isotachic H^+ ($Z_p = 1$) impact, yielding cross section ratios $R = DDCS(Z_p)/DDCS(Z_p = 1)$ as a function of ejected-electron energy E_e . Assuming a Z_p^2 scaling of the DDCS effective projectile charges $Z_{eff} = R^{1/2}$ were calculated as a function of an effective interaction distance, the so-called adiabatic radius, given by $b_{eff} = \hbar v_p / \Delta E$, where $\Delta E = I_b + E_e$ is the collisional energy transfer with I_b being the binding energy of the target electron (cf. [12]). This is shown in figure 2 for H_2^+ and $^3He^+$ ions obtained from collisions with He at 1.7 MeV/u and $\theta_{lab} = 42.5^\circ$. At large values of b_{eff} corresponding to distant collisions with small energy transfer the experimental points clearly show a screening, with $^3He^+$ being stronger screened than H_2^+ . At small values of b_{eff} corresponding to close collisions with large energy transfer no screening is observed within the experimental errors (the data points here are averages from the electron energy region above the ELC-peak). The theoretical curves taking into account projectile screening and derived from cross section ratios also, reflect the shape of the experimental data quite well, with $^3He^+$ also being stronger screened than H_2^+ . The disagreement in absolute values at large b_{eff} may be due to contributions of the ELC-peak (not shown in Fig. 2) lifting up the experimental points. For $^3He^{++}$ (2.0 MeV/u) incident on He no screening was found in the whole energy range studied; these yield a mean $\bar{Z}_{eff} = 2.02 \pm 0.10$ in accordance with the Z_p^2 scaling. The findings, as shown in figure 2, are qualitatively the same for all collision systems studied (cf. [4, 12]). The angular dependence of the screening effect as found by the calculations is too small to be observed within the experimental errors. The mean cross section ratio $\bar{R} = 1.89 \pm 0.22$ in the electron energy region above the ELC-peak supports the assumption made in the calculations that the H_2^+ molecule can be treated as consisting of H^0 and H^+ acting independently [13]. The effective projectile charge of H_2^+ was calculated therefore from the cross section ratios R by $Z_{eff}(H_2^+) = Z_{eff}(H^0) + Z(H^+) = |R - 1|^{1/2} + 1$.

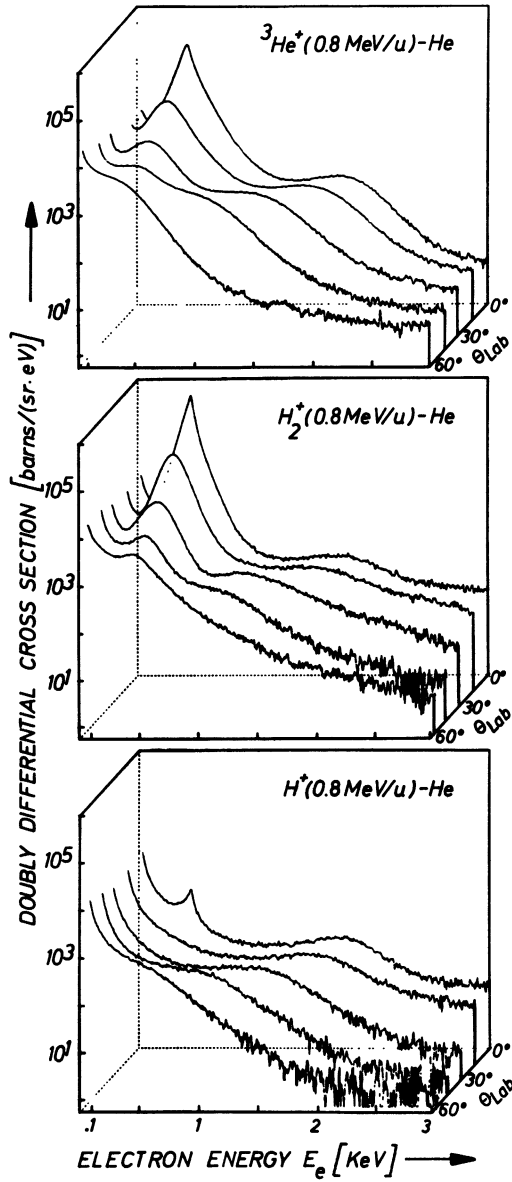


Fig. 1. — Typical electron spectra measured for the collision systems indicated. The absolute double differential cross section (per molecule) is plotted as a function of ejected-electron energy E_e at electron emission angles $\theta_{\text{lab}} = 0^\circ, 15^\circ, 30^\circ, 42.5^\circ,$ and 55° (60° at ${}^3\text{He}^+$ impact).

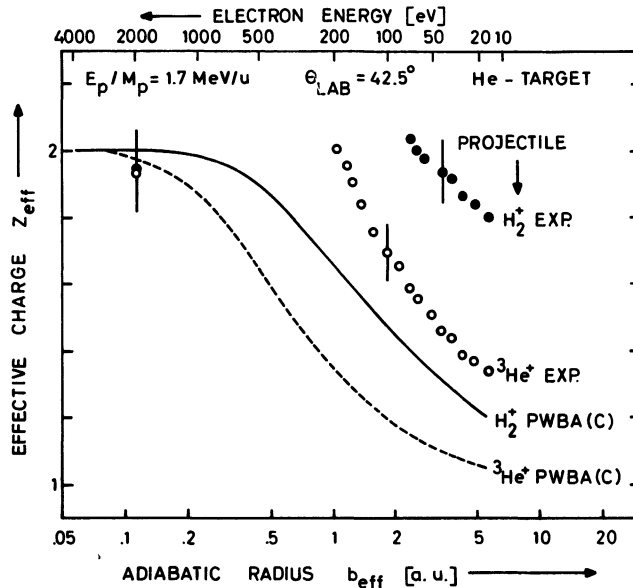


Fig. 2. — Effective projectile charges Z_{eff} plotted against the adiabatic radius b_{eff} (in atomic units) for H_2^+ and ${}^3\text{He}^+$ incident on He with projectile energy $E_p/M_p = 1.7$ MeV/u at an electron emission angle $\theta_{\text{lab}} = 42.5^\circ$. The theoretical curves PWBA(C) were calculated taking projectile screening into account. It was assumed that $Z_{\text{eff}}({}^3\text{He}^+) = R^{1/2}$ and $Z_{\text{eff}}(\text{H}_2^+) = Z_{\text{eff}}(\text{H}^0) + Z(\text{H}^+) = |R - 1|^{1/2} + 1$.

To investigate the electron loss process, angular and projectile energy dependencies of the single differential cross section (SDCS) $d\sigma/d\Omega$, the peak width and the peak position of the ELC-peaks were determined for the collision systems studied (cf. [11, 14]). In figure 3 absolute SDCS of the ELC-peaks measured in H_2^+ (0.8 MeV/u)-He collisions are shown as a function of electron emission angle θ_{lab} . A comparison with the PWBA calculations (A : no screening, B : screening and simultaneous excitation, C : screening, and D : Thomas-Fermi screening of the target atom, respectively) clearly demonstrates a screening effect in the production of ELC-electrons at small electron emission angles. A screening is also indicated by comparing the SDCS of ELC-peaks from H_2^+ (1.1 MeV/u) incident on Ar ($Z_p = 18$) and He ($Z_p = 2$). From the Z_p^2 scaling a cross section ratio $R = 81$ is expected, while experimental ratios of R rising from 6 to 10 with increasing θ_{lab} are observed. In all the collision systems studied the SDCS of the ELC-peaks decrease with increasing θ_{lab} (see Fig. 3) and increasing projectile energy, the projectile energy dependence being weak at small θ_{lab} .

The widths (FWHM) of the ELC-peaks are found to increase rapidly with emission angle (cf. Fig. 1), exhibiting a hump at $\theta_{\text{lab}} \approx 40^\circ$, while the theoretical widths, also rising steeply at small angles, show a slight continuous increase for $\theta_{\text{lab}} \geq 15^\circ$. A close inspection of the ELC-peak shapes reveals a shoulder on the low-energy side with intensities up to 20% of the ELC yield, whose energy position changes as $\cos^2 \theta_{\text{lab}}$. This angular dependence and the energy position of the shoulder may indicate an electron-electron scattering process yielding a binary ridge in the spectrum [13]. The generally larger widths of the ELC-peaks for ${}^3\text{He}^+$ impact on He compared to that of H_2^+ impact reflect the different electron momentum distributions in ${}^3\text{He}^+$ and H_2^+ . Within the experimental errors the widths are found to be independent on the target for H_2^+ (1.1 MeV/u) incident on He and Ar. The position of the ELC-peak maximum shifts to lower electron energies with increasing emission angle. The shifts, generally larger for ${}^3\text{He}^+$ impact compared to H_2^+ impact, increase slightly as a function of projectile energy.

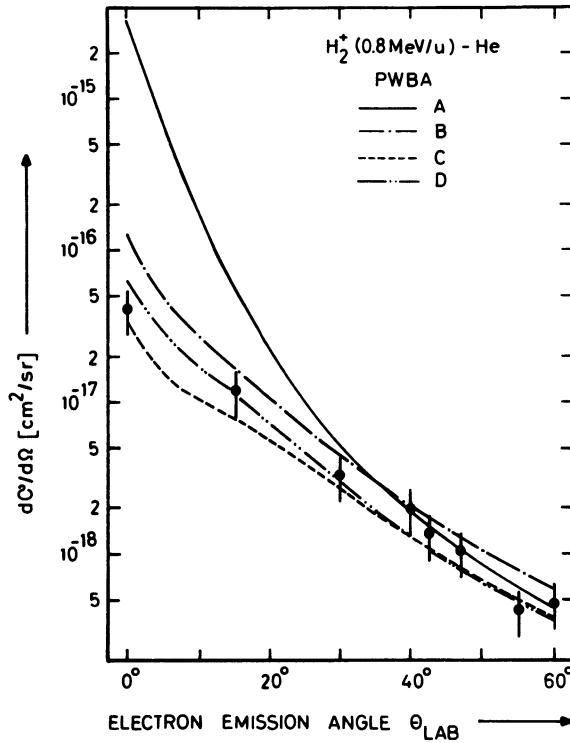


Fig. 3. — Absolute single differential cross sections (per molecule) for projectile electron loss (ELC) plotted against the electron emission angle θ_{lab} , for the collision system H_2^+ (0.8 MeV/u)-He. The experimental data are compared to PWBA calculations using different approximations (A : without screening, B : screening and simultaneous excitation, C : screening, D : Thomas-Fermi screening of the target atom respectively).

In summary, it can be stated that the target ionization and the dependencies of the ELC-peaks observed in this study are qualitatively well described by the PWBA calculations if a screening of the ionizing particle is included. A detailed discussion will be published later [10].

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References

- [1] BREINIG, M., ELSTON, S. B., HULDT, S., LILJEBY, L., VANE, C. R., BERRY, S. D., GLASS, G. A., SCHAUER, M., SELLIN, I. A., ALTON, G. D., DATZ, S., OVERBURY, S., LAUBERT, R. and SUTER, M., *Phys. Rev. A* **25** (1982) 3015.
- [2] MANSON, S. T., TOBUREN, L. H., *Phys. Rev. Lett.* **46** (1981) 529.
- [3] MCGUIRE, J. H., STOLTERFOHT, N., SIMONY, P. R., *Phys. Rev. A* **24** (1981) 97.
- [4] KÖVÉR, A., SZABÓ, Gy., BERÉNYI, D., VARGA, D., KÁDÁR, I., RICZ, S., *J. Végh. Phys. Lett. A* **89** (1982) 71.
- [5] DREPPER, F., BRIGGS, J. S., *J. Phys. B* **9** (1976) 2063.

- [6] BERÉNYI, D., KÓLTAY, E., KÖVÉR, A., RICZ, S., SZABÓ, Gy., VÉGH, J., GROENEVELD, K. O., SCHADER, J., International Seminar *High-Energy Ion-Atom Collision Processes*, Debrecen/Hungary, March 1981, *Atomki Bulletin* **23**, No. 1 (1981) 16.
 - [7] SCHADER, J., FRISCHKORN, H. J., KOSCHAR, P., LATZ, R., PFENNIG, J., GROENEVELD, K. O., BERÉNYI, D., KÖVÉR, A., SZABÓ, Gy., *European Conference on Atomic Physics (EPS)*, Heidelberg/Germany, Book of Abstracts **5A**, Part II (1981) 820.
 - [8] LATZ, R., ASTNER, G., FRISCHKORN, H. J., KOSCHAR, P., PFENNIG, J., SCHADER, J., GROENEVELD, K. O., *Nucl. Instrum. Meth.* **194** (1982) 315.
 - [9] RUDD, M. E., TOBUREN, L. H., STOLTERFOHT, N., *Acts Data Nucl. Data Tables* **18** (1976) 413 and **23** (1979) 405.
 - [10] SCHADER, J., LATZ, R., BURKHARD, M., FRISCHKORN, H. J., HOFMANN, D., KOSCHAR, P., GROENEVELD, K. O., BERÉNYI, D., KÖVÉR, A., SZABÓ, Gy., to be published.
 - [11] KÖVÉR, A., VARGA, D., SZABÓ, Gy., BERÉNYI, D., KÁDÁR, I., RICZ, S., VÉGH, J., HOCK, G., *J. Phys. B* **16** (1983) 1017.
 - [12] TOBUREN, L. H., ZIEM, P., STOLTERFOHT, N., SCHNEIDER, D., PROST, M., *IEEE NS* **28** (1981) 1131.
 - [13] WILSON, W. E., TOBUREN, L. H., *Phys. Rev. A* **7** (1973) 1535.
 - [14] DUNCAN, M. M., MENENDEZ, M. G., *Phys. Rev. A* **19** (1979) 49.
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