Cross Sections for Electron Stripping of Light Fully Stripped Ions by Hydrogen and Helium Atoms

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Ions may lose electrons as they pass through residual gas in accelerators, beam transport lines, and target chambers. As a result, the ion beam transmission and the quality of beam focus are reduced. Therefore, it is important to assess the values of projectile stripping cross sections in ion–atom collisions. In contrast to ionization by electrons and protons, where extensive experimental and theoretical results exist for a large variety of atoms and ions, the knowledge of cross sections for stripping of fast complex ions by atoms is far from complete [1]. Here we use the term “stripping” for projectile electron loss in a collision with a stationary atom or an ion, and the term “ionization” for target electron loss in the collision with a projectile. However, the two terms describe the same process from two different frames of reference, and so the same approach can be used to describe both stripping and ionization.

In Fig. 1, the measured cross sections [2] for ionization of a hydrogen atom in a collision with selected light fully stripped light ions (H⁺, He2⁺, Li3⁺, and C6⁺) are compared with predictions of the existing theories as a function of the projectile scaled speed. The scaled projectile speed is the projectile speed (v) divided by the average orbital speed of the target electron (v_{nl}). Evidently, the Bethe formula [3] is good for projectile speeds larger than the average electron orbital speed. At large projectile speed, the Gerjuoy, Garcia and Vriens (GGV) formula [4] underestimates the cross sections, whereas the Gryzinski formula [5] yields results close to those of the Bethe formula and the experimental data. The Bethe, GGV and Gryzinski formulas all fail at small projectile speeds because they assume that target electrons are localized and neglect their motion during the collision.

Here we propose a new semiempirical formula that has no fitting parameters and is correct for small and large projectile speeds:

Figure 1. Scaled cross-sections for ionization of atomic hydrogen by selected fully stripped ions. Both experimental data [2] and theoretical curves are shown. Bethe stands for Bethe’s quantum-mechanical calculation in the Born approximation [3] limited to v > v_{nl}, GGV stands for the classical calculation by Gerjuoy using the fitted target electron velocity distribution of Garcia and Vriens [4], and Gryz denotes the Gryzinski approximation [5]. Finally, BA denotes the Born approximation in the general case [6]. All values are in atomic units.
\[
\sigma = \pi a_o^2 \frac{Z_p^2 E_o^2}{Z_p + 1 I_{nl}^2} G(V),
\]

where

\[
G(V) = \exp(-V^{-2})[1.26 + 0.283 \ln(2V^2 + 25)]/V^2
\]

and

\[
V = \frac{v}{v_{nl} \sqrt{Z_p + 1}}.
\]

Here \(\sigma\) is the cross section for ionization of a hydrogen target atom, \(a_o = 52.9\) pm is the Bohr radius, and \(Z_p\) is the projectile atomic number, and \(I_{nl} / E_o = 0.5\) is the ionization potential of hydrogen in its ground state expressed in atomic units \((E_o = 27.2\) eV).

The cross sections scaled based on eqs. (1-3) are shown in Fig. 2. Evidently the scaling shown in Fig. 2 is much better than the scaling shown in Fig. 1, as the presented experimental data in Fig. 2 seem to outline a universal curve. The newly proposed semiempirical formula [eqs. (1-3)] was also found to apply to the collisions involving helium target atoms.


\[\text{[3]}\text{ H. Bethe, Ann. Phys. (Leipz.) 5, 325 (1930).}\]


\[\text{[5]}\text{ M. Gryzinski, Phys. Rev. A 138, 322 (1965).}\]

