

Stopping Power of Multiply Charged Ions

Sabin, John R.

Published in:
Journal of Physical Chemistry & Biophysics

DOI:
[10.4172/2161-0398.1000e132](https://doi.org/10.4172/2161-0398.1000e132)

Publication date:
2016

Document version
Final published version

Citation for pulished version (APA):
Sabin, J. R. (2016). Stopping Power of Multiply Charged Ions. *Journal of Physical Chemistry & Biophysics*, 6(1), [1000e132]. <https://doi.org/10.4172/2161-0398.1000e132>

Terms of use

This work is brought to you by the University of Southern Denmark through the SDU Research Portal. Unless otherwise specified it has been shared according to the terms for self-archiving. If no other license is stated, these terms apply:

- You may download this work for personal use only.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying this open access version

If you believe that this document breaches copyright please contact us providing details and we will investigate your claim. Please direct all enquiries to puresupport@bib.sdu.dk

Stopping Power of Multiply Charged Ions

John R Sabin^{1,2*}

¹Institut for Fysik, Kemi of Farmaci, Syddansk Universitet, Odense Denmark

²Department of Physics, Quantum Theory Project, University of Florida, Gainesville, Florida, USA

Fast ions, such as protons and alphas, interact with, and deposit energy in, target ions and molecules by converting kinetic energy of the projectile to target electronic energy. Such energy deposition occurs in situations as different as deep space and plasmas and can involve targets as different as atomic ions and rather complicated organic molecules [1]. In most cases, the deposition of electronic energy by a fast ion with velocity v in a target of scatterer particle density n is described by the equation:

$$-\frac{dE}{dx} = nS(v) \quad (1)$$

Where $S(v)$ is the stopping cross section of the target and, in the Bethe approximation [2] which assumes the projectile velocity is much larger than the target electron velocities, is given by:

$$S(v) = \frac{4\pi e^4 Z_1^2 Z_2}{mv^2} \ln \frac{2mv^2}{I_0} \quad (2)$$

Here Z_1 and Z_2 are the projectile charge and target electron number, respectively, and I_0 is the target mean excitation energy. The mean excitation energy is defined [3] as the first energy weighted moment of the dipole oscillator strength distribution:

$$\ln I_0 = \frac{\int \frac{df}{dE} \ln EdE}{\int \frac{df}{dE} dE} \quad (3)$$

The determining factor for the amount of electronic energy deposited in a target by a fast ion. Thus, for electronic energy deposition by a fast ion at a given velocity in a target, the larger the mean excitation energy of target, the less electronic energy will be deposited. It should also be noted that the target may fragment or some projectile energy may be transferred to the target nuclear kinetic energy, but those possibilities are not considered here.

As an example, consider the simple case of protons colliding with an aluminum ion [3]. Although Aluminum ions are not frequently found in either plasmas or free space, $Alq+$ is chosen as an illustration as it has enough electrons, and thus enough differently charged ions, that changes in stopping properties with ionic charge can be illustrated. The table presents the calculated mean excitation energy [4] and stopping cross section for a proton with an (arbitrary) velocity of 20 a.u. (10 MeV) colliding with various aluminum ions. This is an arbitrary projectile velocity chosen for illustration only. Any other Bethe acceptable projectile velocity would give qualitatively similar results. No values for the stopping cross section are given for Al^{11+} and Al^{12+} as the velocity of the 1s electrons in Al is larger than the projectile velocity, and thus the Bethe approximation does not apply. Otherwise, the results are as expected with the increasing mean excitation energy of more highly charged ions leading to a decrease in stopping cross section.

It is also interesting to note that the largest changes in the mean excitation energy with ion charge, and thus in the stopping cross section as well, come when the outermost electrons, which give the largest contribution to the stopping cross section, come from differing

	I_0 (au)	$S(v=20)$ (au)
Al	4.851	1.145
Al ¹⁺	6.366	0.956
Al ²⁺	8.283	0.784
Al ³⁺	11.407	0.612
Al ⁴⁺	12.881	0.516
Al ⁵⁺	14.630	0.427
Al ⁶⁺	16.746	0.343
Al ⁷⁺	19.709	0.264
Al ⁸⁺	24.063	0.189
Al ⁹⁺	31.865	0.116
Al ¹⁰⁺	45.507	0.053
Al ¹¹⁺	88.452	*
Al ¹²⁺	92.726	*

Table 1: Mean Excitation Energies and Stopping Cross Sections for $v = 20$ a.u. Protons colliding with Aluminum Ions.

electronic subshells, such as $Al^{2+} \rightarrow Al^{3+}$, $Al^{8+} \rightarrow Al^{9+}$, and $Al^{10+} \rightarrow Al^{11+}$ (Table 1).

Similar results are found for many other of the light ions [4]. Although similar studies have not yet been carried out for heavier atomic ions, similar results are to be expected.

If the target is a molecule or molecular ion, things are much more complicated. In principle the same collision of an ion with a polyatomic target leads to the same conversion of projectile kinetic energy to electronic energy and deposition of electronic energy in the target. Although each target atomic ion has a well-defined mean excitation energy, the same is not true for polyatomic targets. For molecules, the mean excitation energy depends on the molecular conformer [5] and orientation of the target with respect to the projectile [6]. In addition, while an atomic ion can be excited or ionized, a polyatomic target can be excited, ionized, fractionated, reoriented, or some combination of the foregoing.

Due to the complications mentioned here, very little has been done on polyatomic targets. Little has been done here, but much more work needs to be done, both theoretically and experimentally.

Another, as yet to be theoretically studied system is energy deposition by a polyatomic projectile!

***Corresponding author:** John R Sabin, Department of Physics, Quantum Theory Project, University of Florida, Gainesville, FL, USA, Tel: 352/392-1597; E-mail: sabin@qtp.ufl.edu

Received January 23, 2016; **Accepted** January 25, 2016; **Published** January 27, 2016

Citation: Sabin JR (2016) Stopping Power of Multiply Charged Ions. J Phys Chem Biophys 6: e132. doi:10.4172/2161-0398.1000e132

Copyright: © 2016 Sabin JR. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

References

1. Belloche A, Garrod RT, Muller HS, Menten KM (2014) Detection of a branched alkyl molecule in the interstellar medium: iso-propyl cyanide. *Science* 345: 1584-1587.
2. Bethe H (1930) Zur Theorie des Durchgangs schneller Koepuskularstrahlen durch Materie. *Ann Phys (Leipzig)* 5: 325-400.
3. Inokuti M (1971) Inelastic Collisions of Fast Charged Particles with Atoms and Molecules – The Bethe Theory Revisited. *Rev Mod Phys* 43: 197-347.
4. Sauer SPA, Oddershede J, Sabin JR (2015) The Mean Excitation Energy of Atomic Ions. *Adv Quantum Chem* 71: 29-40.
5. Sabin JR, Oddershede J, Sauer SPA (2013) Glycine: Theory of the Interaction with Fast Ion Radiation. In *Glycine: Biosynthesis, Physiological Functions and Commercial Uses*. Wilhelm V (ed). NOVA Publishers. pp: 79-96.
6. Sabin JR, Cabrera-Trujillo R, Stolterfoht N, Deumens E, Öhm Y (2009) Fragmentation of Water on Swift 3He^{2+} Ion Impact. *Nucl Inst and Meth B* 267: 196-200.

Citation: Sabin JR (2016) Stopping Power of Multiply Charged Ions. J Phys Chem Biophys 6: e132. doi:10.4172/2161-0398.1000e132

OMICS International: Publication Benefits & Features

Unique features:

- Increased global visibility of articles through worldwide distribution and indexing
- Showcasing recent research output in a timely and updated manner
- Special issues on the current trends of scientific research

Special features:

- 700 Open Access Journals
- 50,000 editorial team
- Rapid review process
- Quality and quick editorial, review and publication processing
- Indexing at PubMed (partial), Scopus, EBSCO, Index Copernicus, Google Scholar etc.
- Sharing Option: Social Networking Enabled
- Authors, Reviewers and Editors rewarded with online Scientific Credits
- Better discount for your subsequent articles

Submit your manuscript at: <http://www.omicsonline.org/submission>