A new stopping power parameterization for 0.5-15 MeV/nucleon heavy and superheavy ions in solids and gases

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Electronic stopping powers of heavy ions in several media are deduced from the corresponding proton data by using new effective charge parameterizations. Separate sets of parameters were deduced for solid and gaseous materials using the available data for heavy ions in the energy range from 0.5 to 15 MeV/nucleon. Using these results, predictions are made for stopping powers of heavy and superheavy elements with Z=100 to 130 in the energy range of 0.5 to 15 MeV/nucleon.

In a given stopping medium, the stopping power (S_I) of an ion is related to that of a reference ion (S_{Ref}) with the same velocity by the scaling law

$$\frac{S_I}{(\gamma_I Z_I)^2} = \frac{S_{\mathrm{Ref}}}{Z_{\mathrm{Ref}}^2} \tag{1}$$

where $\gamma_I Z_I$ is the effective charge of the ion with atomic number Z_I. In this equation, the reference ion having atomic number Z_{Ref} is assumed to be fully stripped.

The effective charge fraction γ can be defined empirically by

$$\gamma^2 = \frac{S_I(v, Z_I, \mathrm{target}) / Z_I^2}{S_{\mathrm{Ref}}(v, Z_{\mathrm{Ref}}, \mathrm{target}) / Z_{\mathrm{Ref}}^2} \tag{2}$$

where v is the ion velocity and “target” labels the stopping material.

We use protons as reference ions since they can be fully stripped at lower energies than ^{4}He. The proton stopping powers are obtained using the SRIM-2008 code [1], a widely employed stopping power tool. Using these reference stopping powers, the effective charge values, γ were extracted using relationship (2) and the experimental stopping powers for Ar, Kr, Au, Pb and U ions in solid and gaseous materials.

The empirical γ values were then reproduced using the relationships:

$$\begin{aligned} \gamma &= 1 - P_0 \exp(-P_1 E_A^{p_2} / Z^{p_3}) \\ P_0 &= p_0 + p_1 \ln(Z) \\ P_1 &= p_4 + p_5 \ln(Z) \end{aligned} \tag{3}$$

where p_0, p_1, p_2, p_3, p_4 and p_5 are fitting parameters, Z is the atomic number of the ion and E_A is the specific energy in MeV/nucleon.

The available experimental stopping powers for Ar, Kr, Au and U ions in isobutane [2] (258 experimental points in the energy range from 0.1 to 15 MeV/nucleon) were used to determine the parameters for gaseous media, whereas data relative to the same projectiles but in aluminum, silver, gold and mylar were used for solid media [2,3].

To assess the quality of our work, Fig. 1 shows how results of our parameterization compare with the SRIM-2008 and Hubert predictions [4] and with the experimental stopping powers of Ar and U in Aluminum. It is clear that, while for Ar ions the quality of all the calculations is comparable, for U ions our parameterization gives the best reproduction of the experimental data.

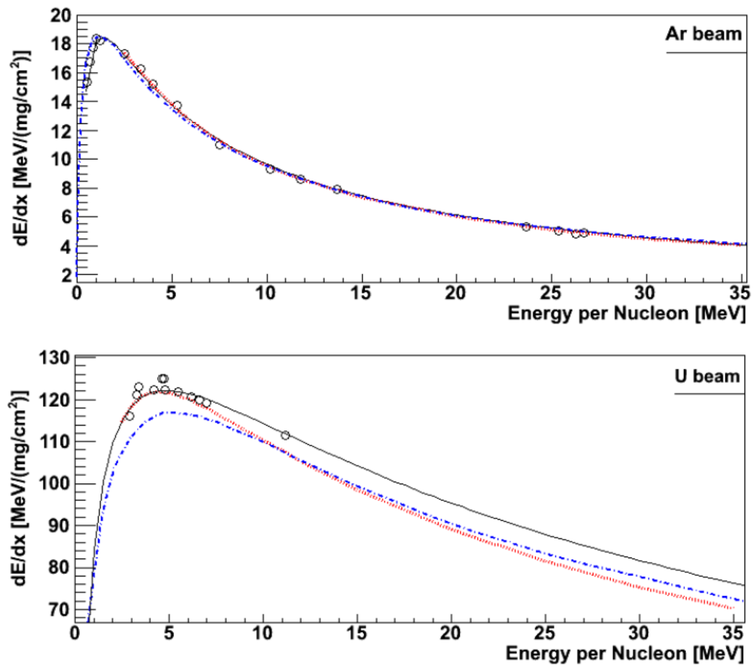

FIG. 1. Comparison of experimental stopping powers for Ar and U in aluminum (open circles) with the values calculated using our parameterization of the effective charge data (black solid line), using SRIM-2008 (blue dot-dashed line), using the Hubert tables (red dotted line)

Our parameterization is valid for projectiles with atomic number from Z=18 to Z=92 in the energy range from 0.5 to 15 MeV/nucleon, for the tested stopping materials. On average, in the energy range from 1.5 to 15 MeV/nucleon, the predicted stopping powers agree with the experimental data to within 5% whereas the agreement is to within 10% for lower energies.

Given the good reproduction of the stopping powers of high Z projectiles we believe that we can extrapolate the results to ions with atomic number larger than 100. Therefore the parameterization was used to predict stopping power values for superheavy elements with Z>100 in Al, mylar and isobutane. The results are shown in Fig. 2.

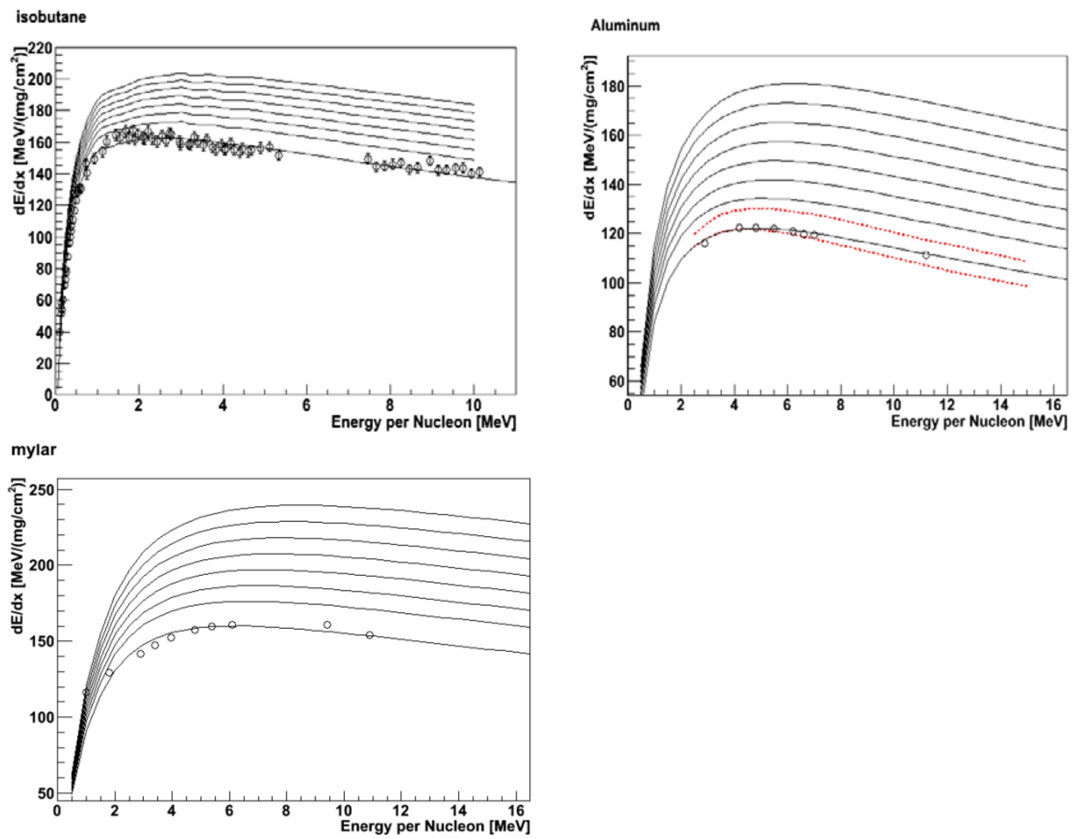

FIG. 2. The calculated stopping powers of heavy ions with atomic number Z=92, 100, 105, 110, 115, 120, 125, 130 in isobutane, aluminum and mylar are shown as a function of the specific energy (solid lines). For comparison, the measured stopping powers of U (Z=92) ions are also shown (open circles). The dashed lines in the Al target figure represent the prediction of the Hubert tabulations for Z=92 and Z=100.

[1] http://www.srim.org

[2] M. Barbui *et al.*, Nucl. Instrum Methods Phys. Res. **B268** ,20 (2010).

[3] A collection of experimental data is available at the H. Paul web page (http://www.exphys.uni-linz.ac.at/stopping/).

[4] F. Hubert *et al.*, At. Data Nucl. Data Tables **46**, 1 (1990).