GSI-2016-2
REPORT
June 2016

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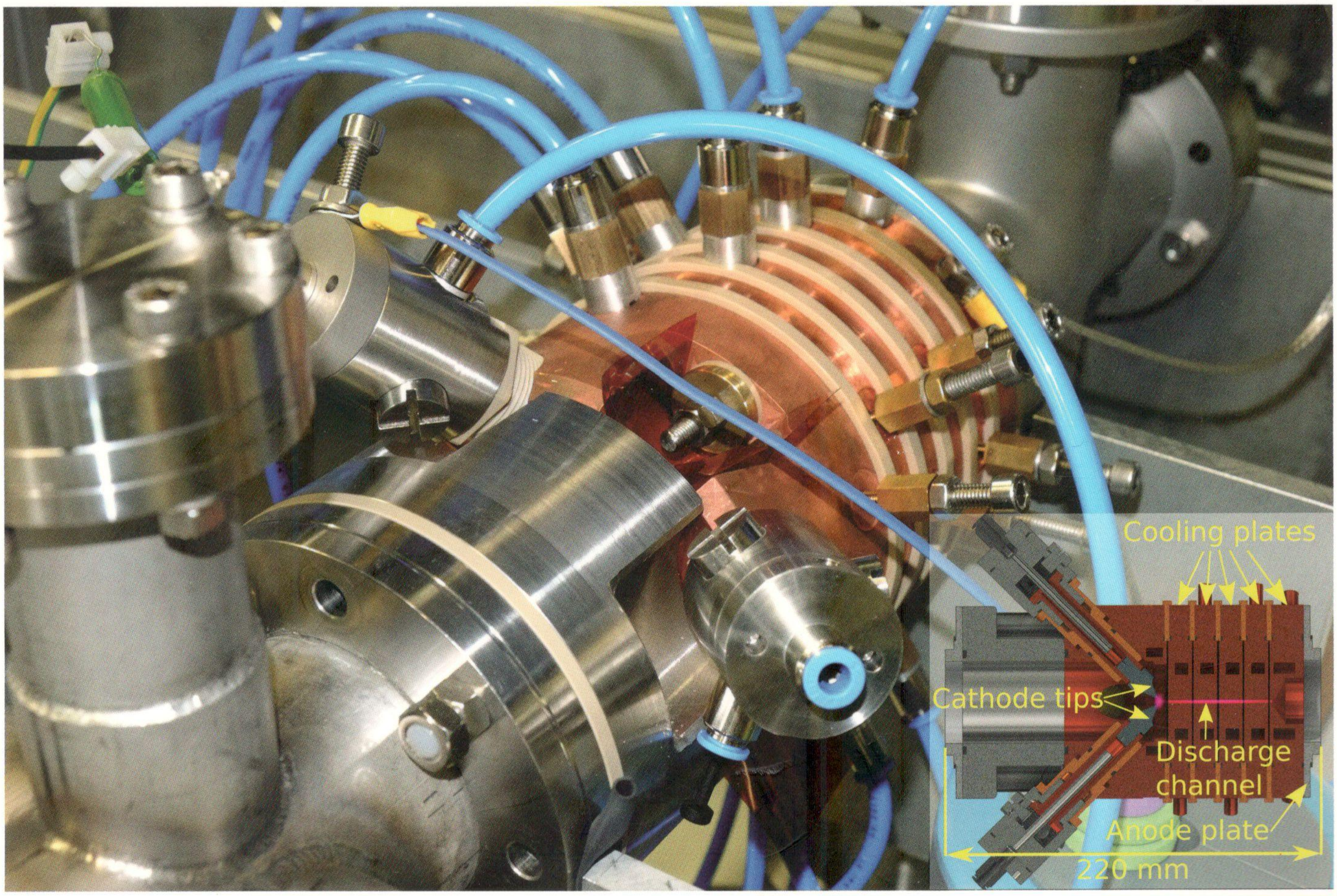

HEDgeHOB Collaboration at FAIR – Report 2015

The corrected Bethe-Larkin formula applied*

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Abstract: The corrected Bethe-Larkin formula for the non-ideal plasma stopping power asymptotic form is successfully applied to recent experimental data.

In 1930, Bethe derived his seminal formula for the fast projectile energy losses assuming that the atoms of the medium behave as quantum-mechanical oscillators [1]. Thirty years later, Larkin [2] showed that when fast ions transpire an electron gas, the same formula is applicable, but with the mean atomic ionization potential I replaced by the plasma frequency ω_p:

$$S(v \to \infty) \cong \left(\frac{Z_p e \omega_p}{v}\right)^2 \beta a \ln \frac{2mv^2}{\hbar\omega_p}, \qquad (1)$$

where $Z_p e$, and v stand for the charge and velocity of a projectile, β^{-1}, a and m are the plasma temperature in energy units, the electronic Wigner-Seitz radius and mass, $\hbar$ is the Planck constant, and $S(v)$ is the dimensionless plasma stopping power. This formula is often employed to determine experimentally the number density of electrons, n_e, in a charged particle system [3].

Leaving the ionization losses and other effects like the Barkas [4] one aside, for calculating the stopping power of a fast projectile passing through a Coulomb fluid we adopted the polarizational picture [5]. Then the expression for the stopping power can be simplified by applying the Fermi golden rule [6]:

$$S(v) = \left(\frac{Z_p e}{v}\right)^2 \frac{2\beta a}{\pi} \int_0^\infty \frac{dk}{k} \int_0^{kv} \omega^2 L(k,\omega) d\omega, \qquad (2)$$

where $L(k,\omega) = -\epsilon^{-1}(k,\omega)/\omega$ and $\epsilon(k,\omega)$ are the plasma loss and dielectric functions. Usually, the interaction of target electrons with the plasma ions is neglected in the stopping power. Nevertheless, the target plasma electron-ion static structure factor $S_{ei}(k)$ influences the plasma polarizational stopping power. This effect was taken into account in [7] using the canonical solution of the Hamburger moment problem in the corrected Bethe-Larkin formula:

$$S_{TCP}(v \to \infty) \cong \left(\frac{Z_p e \omega_p}{v}\right)^2 \beta a \ln \frac{2mv^2}{I_{eff}}. \qquad (3)$$

Here $I_{eff} = \hbar\omega_p\sqrt{1+H}$, $H = \int_0^\infty \frac{p^2 S_{ei}(p)dp}{6\pi^2\sqrt{n_e n_i}}$ and $n_i = Zn_e$ is the number density of ions of charge Ze in the system. The previous result (3) contrasts with the case of energy losses in one-component plasmas (OCPs), where the Bethe-Larkin formula (1) is not modified by the electron-electron correlations [8]. The electron-ion correlations should be accounted for along other effects like the influence of core electrons [9] on the stopping power of complex plasmas.

We have carried out some calculations based on the results of the recent work [9] and a reasonable agreement has been found between the precalculated values of the mean ionization potential in warm dense matter [9]:

$$\bar{I} \in [38.9, 48.8]\ eV$$

and our effective ionization potential. We have determined the effective number density of electrons corresponding to the plasmon energy $\hbar\omega_p$ of about 27 eV (see Fig. 5b from [9], see below): $n_e \approx 5.3 \cdot 10^{23}\ cm^{-3}$ ($Z = 1.82$), the temperature was assumed to belong to the error interval [9], $\beta^{-1} \in (17, 47)\ eV$ and calculated the coupling parameter H. The values of the latter turned out to be $H \in [0.92, 1.515]$ so that the effective potential determined by the target ions, $I_{eff} = \hbar\omega_p\sqrt{1+H} \in [37.4, 42.8]\ eV$, overlaps with the data provided in Fig. 5b of [9]. The H parameter was computed in the hyper-netted chain approximation for the Deutsch potential. More experimental studies are needed for further verification of the presented results.

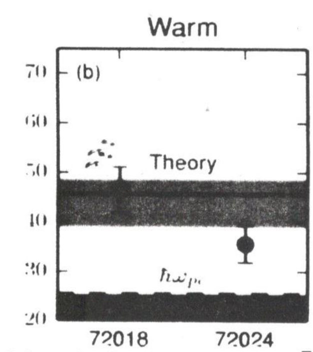

Fig. 5(b) [9]. Mean ionization potential ($\bar{I}$) inferred from the stopping power data obtained for two different experimental shots in the warm case compared to the ideal plasma theory ($\hbar\omega_{pe}$) and electronic structure theory.

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* Work supported by the Republic of Kazakhstan Ministry of Education and Science grant No.3119/GF4 and by the Spanish Ministerio de Economía, Ciencia e Innovación Project ESP2013-41078-R.
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