Ionization length in a plasma of arbitrary ionization degree

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Abstract

This text was written in order to answer frequently asked questions concerning the ionization length.

1 What is the ionization length?

The concept of ionization length in a plasma of arbitrary ionization degree has been discussed in detail in Appendix B of [1].

2 What is physical meaning of the ionization length?

Let us consider the general case where the density of the ions and the electrons is comparable to the density of neutral particles while the electron temperature is comparable to the heavy-particle temperature. Then it follows from Eq. (17) of [1, Appendix B] that the ionization length d may be estimated by order of magnitude as

$$d = \sqrt{\frac{D_{ia}}{k_i n}}, \tag{1}$$

where D_{ia} is the coefficient of diffusion ion-atom, k_i is the rate constant of ionization of atoms by electron impact, and n is a characteristic particle density.

Time necessary for an atom to diffuse over the distance d may be estimated as

$$\tau = \frac{d^2}{D_{ia}}. \tag{2}$$

Using Eq. (1), one finds

$$\tau = \frac{1}{k_i n}. \tag{3}$$

The product $k_i n$ represents the ionization frequency per atom. Hence, $1/k_i n$ is a characteristic time necessary for ionization of an atom. Thus, we have found a physical meaning of the ionization length: it is a characteristic distance over which an atom diffuses before being ionized.

3 Is there any relation between the ionization length and the electron-atom mean free path?

If the density of the ions and the electrons is comparable to the density of neutral particles, the electron-atom mean free path is defined as $\lambda_{ea} = 1/nQ_{ea}$, where Q_{ea} is a characteristic cross section of collisions electron-atom. D_{ia} is of the order of C_i/nQ_{ia}, where C_i is a characteristic velocity of chaotic motion of the ions and Q_{ia} is a characteristic cross section of collisions ion-atom. Finally, $k_i = C_e Q_{ion}$, where C_e is a characteristic velocity of chaotic motion of the electrons and Q_{ioniz} is the ionization cross section. One finds

$$\frac{d}{\lambda_{ea}} = \sqrt{\frac{C_i Q_{ea}^2}{C_e Q_{ioniz} Q_{ia}}}. \tag{4}$$

The ratio C_i/C_e is much smaller than unity. The ratio Q_{ea}/Q_{ia} is usually also much smaller than unity. The ratio Q_{ea}/Q_{ioniz} is larger than unity, however usually it is not dramatically high, at least in the case of a hot arc plasma. As a consequence, the ratio d/λ_{ea} is usually much smaller than unity.

References

[1] M. S. Benilov, J. Phys. D: Appl. Phys. **32**, 257 (1999).