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INTERPOLATION FORMULA FOR REFLECTION COEFFICIENT OF keV LIGHT IONS FROM SOLIDS UPON ANGLE OF INCIDENCE

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Abstract. The particle reflection coefficient of light keV ions backscattered from heavy targets as a function of the angle of ion incidence has been determined by a suitable interpolation formula. The formula has two fitting parameters which are obtained by using results of two limiting analytic approaches: by the single collision model in case of nearly perpendicular incidence and by the small-angle multiple scattering theory in case of glancing angles of incidence. The obtained interpolation formula is a universal function of the scaled transport cross section and the angle of incidence.

1. INTRODUCTION

Reflection of light ions from heavy solid targets is very important for the field of interaction between the fusion plasma and the first wall of the fusion reactor. The particle and energy reflection coefficients for normal incidence of ions have been studied theoretically by a number of authors (Eckstein and Verbeek 1979, Tilinin 1984, Luo 1990, Vicanek and Urbassek 1991, Vukanić and Simović 2004). However, for oblique ion incidence the theoretical results for the reflection coefficients are rather limited (Tabata et al. 1985, Vicanek and Urbassek 1991).

The purpose of this work is to study the variation of particle reflection coefficient with the angle of incidence. Since light ions penetrate the first wall of the fusion device with a wide range of angles, analytical estimates of ion reflection in the case of oblique and grazing incidence are important. In this report we present an interpolation formula for particle reflection coefficient as a function of angle of ion incidence. This formula is based on results of the single collision model and small-angle multiple collision theory as two limiting cases of ion reflections (Vukanić et al. 1987, Vukanić and Simović 2009), and it is a universal function for all light ion - heavy target combinations.

2. BACKSCATTERING AT OBLIQUE AND GRAZING INCIDENCE

Firstly, we consider backscattering of light ions from heavy solid target in single collision model. A light ion with the initial energy E_0 is incident at an angle α_0 with respect to the inward surface normal and penetrates the target. After an elastic collision with a target atom, the ion can be scattered backwards and can leave the solid. The particle reflection coefficient in single collision approximation $R_{NS}(\nu,\alpha_0)$ has the form (Vukanić and Simović 2009)

$$R_{NS}(\nu,\alpha_0) = (1-m)\,\frac{(3m-1)-2^m(4m-1)+2^{4m-1}m}{2m(4m-1)(3m-1)}\;\nu\;\cos\alpha_0^{-(2m+1)} \tag{1}$$

where m is the exponent in the effective power approximation of the differential cross-section assuming the Thomas-Fermi interaction, and ν is the scaled transport cross-section which represents the mean number of wide angle collisions of an ion during the slowing-down. The parameters m and ν depend of initial ion energy expressed in Thomas-Fermi units. Single collision approximation (1) holds for $\nu \le 1$ and not very oblique ion incidence.

If the incident ions impinge the target at the glancing angles, the ion reflection results from multiple collisions. Our estimates are based on calculations of Remizovich et al. (1980) who solved the transport equation in diffusion approximation and small-angle limit, and have found the path length and angular distribution of ions backscattered from solids. We have obtained the particle reflection coefficient $R_{NG}(\nu,\alpha_0)$ by integrating this solution over all ejection angles and path lengths. Evaluation leads to the asymptotic formula written over $\nu/\cos^2\alpha_0$

$$R_{NG}(\nu/\cos^2\alpha_0) \approx 1-1.162\left(\frac{\cos^2\alpha_0}{\nu}\right)^{1/4}+0.232\left(\frac{\cos^2\alpha_0}{\nu}\right)^{5/4} \tag{2}$$

This expression is accurate within a few percent for $\nu/\cos^2\alpha_0 > 1$.

3. INTERPOLATION FORMULA

In order to obtain the reflection coefficient for an arbitrary angle of incidence we use the empirical formula

$$R_N(\nu,\alpha_0) = R_N(\nu,0^0) + \frac{1-R_N(\nu,0^0)}{1+a\,ctg^b\alpha_0} \tag{3}$$

where $R_N(\nu,0^0)$ is the particle reflection coefficient for perpendicular incidence, and a and b are the fitting parameters. For perpendicular incidence $\alpha_0 = 0$, expression (3) reduces to the exact value $R_N(\nu, 0^0)$, and for very grazing incidence $\alpha_0 = \pi/2$ it approaches the value 1, independently of the initial energy E_0.

The parameters *a* and *b* will be determined by interpolation of the two limiting cases of reflection described by Eqs. (1) and (2). More precisely, we assume that the single collision model holds for $\alpha_0 \leq 45^0$. This assumption yields the fitting parameter *a* from the equation

$$R_N(\nu, 45^o) \approx R_{NS}(\nu, 45^o) \approx R_{NS}(\nu, 0^0) + \frac{1 - R_{NS}(\nu, 0^0)}{1 + a} \quad (4)$$

The fitting parameter *b* is obtained by assuming that small angle multiple collision model and expression (2) hold for $\alpha_0 \geq 75^0$

$$R_N(\nu, 75^o) \approx R_{NG}(\nu, 75^o) \approx R_{NS}(\nu, 0^0) + \frac{1 - R_{NS}(\nu, 0^0)}{1 + a\, ctg^b(75^o)} \quad (5)$$

The particle reflection coefficient in single collision region $\nu \leq 1$ will be calculated from Eq. (3), with the fitting parameters determined from Eqs. (4) and (5), and approximating $R_N(\nu, 0^0) \approx R_{NS}(\nu, 0^0)$.

4. RESULTS

Fig. 1 shows the particle reflection coefficient $R_N(\nu, \alpha_0)$ for light ions backscattered from heavy targets as a function of angle of incidence α_0 for several values of the scaled transport cross-section ν. The results of the single collision model Eq. (1) and the small-angle multiple collision model Eq. (2) are presented by dotted lines, and the interpolation formula Eq. (3), by full lines.

One can see that the interpolation formula agrees well with the results of the single collision model and small-angle multiple collision theory as two limiting cases, and bridges the gap between these theoretical approaches. The main achievement of this treatment is that beam and target physical parameters are condensed to one dimensionless parameter ν, called the scaled transport cross-section, thus describing reflection of all light ions from heavy solid targets. In this way the reflection coefficient is expressed as a universal function of this parameter ν and the angle of incidence α_0.

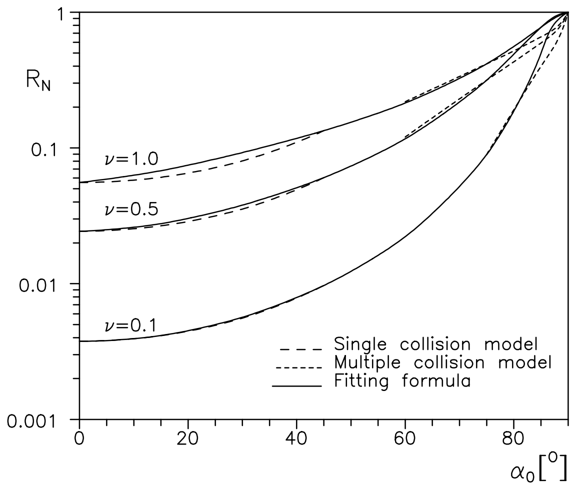

Figure 1: Particle reflection coefficient of light keV ions calculated by the interpolation formula.

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