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Small Angle Rutherford Scattering of H and H^+ by He, Ne and Ar

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Abstract. The relationship between reduced scattering angle $\tau = \theta E$ and impact parameter ϱ in the scattering of H^+ and H by He, Ne, Ar targets has been calculated in the range $.05 \leqslant \varrho \leqslant 1.5$[1]). The results show, that the additional screening in the case of the H-projectile causes a considerable decrease in the impact parameter, thus leading to lower cross sections in the small τ-range.

Introduction

In a recent experiment on the excitation of Lyman-α radiation in collisions of hydrogen with He, Ne and Ar [1], small angle Rutherford scattering was used to monitor the neutral beam intensity. This is a convenient method if the beam intensity is too low to use a thermocouple. The monitor was calibrated by scattering of H^+ from the same targets. To derive the corresponding data for H beams, account has to be taken of the difference in screening effects due to the electron of the hydrogen atom.

Calculations and Results

The relationship between reduced scattering angle $\tau = \theta E$ and impact parameter ϱ is calculated using the classical formula for small scattering angles [2]

$$\tau = -\varrho \int_{\varrho}^{\infty} \frac{\partial U}{\partial R} \frac{dR}{\sqrt{R^2 - \varrho^2}} .$$

Classical calculations are valid if the de Broglie wave length $\lambdabar$ of the incident particle is negligible compared with any significant dimensions of the scattering center and if the scattering angle is well above the uncertainty limit, given by

$$\theta \gg \frac{\lambdabar}{\varrho} . \tag{I}$$

Condition (I) has to be met when using the final results. The potential of the target atom is taken to be [3]

$$V(\tau_1) = \frac{1}{\tau_1} \sum_{\nu} \alpha_{\nu} \, e^{-\tau_1/a_{\nu}}$$

where $\alpha_{\gamma} = 2, 8, 8$ for the K, L and M shell respectively and

$$a_{\nu} = \left(\frac{I_H}{I_{\nu}}\right)^{1/2} .$$

[1]) Atomic units are used.

I_H being the ionization potential of hydrogen and I_ν the closed shell ionization potential of the K, L, M shell of the target atom.

The interaction energy of the target with the incident particle may now be written as (Figure 1)

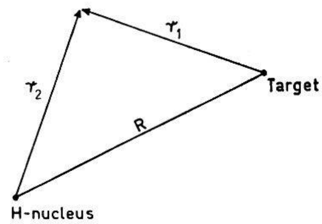

Figure 1

$$U(R) = \int \varrho(r_2)\, V(r_1)\, d\tau\,.$$

In the case of H^+ impact we have:

$$\varrho(r_2) = \delta(r_2)$$

and in the case of H impact:

$$\varrho(r_2) = \delta(r_2) - \frac{1}{\pi}\, e^{-2r_2}$$

$U(R)$ may be evaluated in elliptical coordinates to give

$$U(R) = \sum_\nu \alpha_\nu \left\{\frac{1}{R}\, e^{-R/a_\nu} - \frac{1}{R}\, \frac{32\, a_\nu^4}{(4\, a_\nu^2 - 1)^2}\, (e^{-R/a_\nu} - e^{-2R}) + \frac{8\, a_\nu^2}{4\, a_\nu^2 - 1}\, e^{-2R}\right\}.$$

Equation (1) can now be integrated analytically. The result is

$$\tau = \sum_\nu \alpha_\nu \left\{-\frac{\pi}{2\, a_\nu}\, H_1^1\left(i\, \frac{\varrho}{a_\nu}\right) + \frac{16\, \pi\, a_\nu^4}{(4\, a_\nu^2 - 1)^2}\left[\frac{1}{a_\nu}\, H_1^1\left(i\, \frac{\varrho}{a_\nu}\right) - 2\, H_1^1(2\, i\, \varrho)\right]\right.$$
$$\left. + \frac{8\, a_\nu^2}{4\, a_\nu^2 - 1}\, (i\, \pi\, \varrho)\, H_0^1(2\, i\, \varrho)\right\}.$$

This expression is tedious to handle. The Table has therefore been computed numerically. The quantity listed is the dimensionless number $Z_{eff}(\varrho)$ because it gives a direct measure of the importance of screening effects[2]).

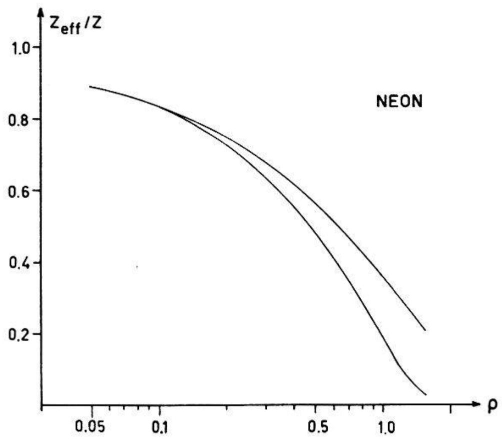

Figure 2

Z_{eff} is plotted against ϱ for a neon target. The upper curve corresponds to proton impact, the lower one to hydrogen impact.

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[2]) Scattering of a bare nucleus of unit charge by a pure Coulomb field Z/R gives $Z_{eff} = Z$.

Figure 2 shows a plot of Z_{eff}/Z against ϱ for H and H^+ impact on Neon ($Z = 10$). It is apparent that in the small τ-range the corresponding cross-sections differ considerably.

Values of Z_{eff}

	Helium		Neon		Argon	
ϱ	H^+	H	H^+	H	H^+	H
0.050	1.829	1.828	8.872	8.864	15.35	15.34
0.065	1.823	1.819	8.722	8.707	14.86	14.84
0.084	1.811	1.805	8.522	8.493	14.23	14.19
0.110	1.794	1.782	8.265	8.212	13.45	13.38
0.143	1.768	1.746	7.946	7.853	12.54	12.41
0.186	1.728	1.691	7.569	7.411	11.49	11.28
0.241	1.671	1.610	7.138	6.879	10.34	9.998
0.314	1.591	1.494	6.659	6.250	9.119	8.588
0.408	1.481	1.334	6.124	5.503	7.892	7.093
0.530	1.337	1.124	5.511	4.609	6.717	5.568
0.689	1.158	0.865	4.794	3.557	5.633	4.070
0.896	0.947	0.575	3.965	2.390	4.629	2.653
1.165	0.717	0.291	3.054	1.240	3.661	1.386
1.514	0.490	0.062	2.136	0.303	2.708	0.386

References

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[3] F. T. Smith, V. International Conference on the Physics of Electronic and Atomic Collisions, Leningrad, U.S.S.R., July 17–23, 1967, Abstracts of Papers, page 181.